

The Violent Earth

Earthquakes, Volcanoes and Tsunamis

The Earth is always active, regardless of whether we can sense it or not. Its interior is restless. There is no part of Earth that is not continually being subject to change. Generally the changes are very slow, occurring through erosion by agents such as water, wind and slow movements of great masses of rock called tectonic plates. But some time the changes are rapid and violent caused by events like earthquakes etc. This book briefly describes in detail three natural phenomena - earthquakes, volcanoes and tsunamis, caused by the violent activities going on inside the Earth and consequences thereof. Different concepts and effects related to these phenomena are the special highlights of the book.

About the author

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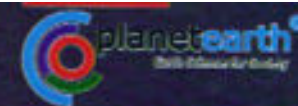
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VIGYAN PRASAR

Sobodh Mahanti

Foreword

Earth is the only planet we know of with life on it. Animals, Plants and microorganisms maintain a delicate balance with a variety of life forms we call Biodiversity. Each species depends on other species for its existence. When we talk of life on earth, we also talk about the human species. If we need to understand and preserve our environment, we shall need to understand the interdependence of the species on each other and the importance of natural resources like air, water and soil for living beings.

Life has continued to evolve on this earth over millions of years adapting to changing environment. Only those species have survived that have adapted to the changing environment. This change could be due to natural causes like earthquakes, eruption of volcanoes, cyclones, and so on. It even could be due to climate change. However, quite often this change is brought about by the species higher up in the ladder of evolution that tries to control environment to suit its needs and for development. This is precisely what human species has done to our fragile planet.

We need energy for development; which we traditionally obtain by burning natural resources like

firewood, coal and petroleum. This is what we have been doing for centuries. Today there is consensus that human activities like burning of fossil fuels and consequent pumping of gases like carbon dioxide into atmosphere have been responsible for the earth getting hotter and hotter. Today, there are threats to our planet arising from climate change, degrading environment, the growing rate of extinction of species, declining availability of fresh water, rivers running dry before they can reach sea, loss of fertile land due to degradation, depleting energy sources, incidence of diseases, challenge of feeding an exponentially growing population, and so on. The human population is now so large that the amount of resources needed to sustain it exceeds what is available. Humanity's environmental demand is much more than the earth's biological capacity. This implies that we are living way beyond our means, consuming much more than what the earth can sustain.

To draw the attention of the world to these aspects and in an attempt to establish that environment is where we live; and development is what we all do in attempting to improve our lot, within that abode, the United Nations has declared the year 2008 as "The Year of the Planet Earth". It is hoped that with the cooperation of all we shall be able to save the biodiversity and the life on this planet. A host of activities and programmes are being organized all over the world for this purpose. One of the important aspects is to make people aware about the challenges we face and the possible solutions to save this planet from heading towards catastrophe. It is with such thoughts that Vigyan Prasar has initiated programmes with activities built around the theme "The Planet Earth". The activities comprise of

development and production of a series of informative booklets, radio and television programmes, and CD-ROMs; and training of resource persons in the country in collaboration with other agencies and organizations.

It is expected that the present series of publications on the theme "The Planet Earth" would be welcomed by science communicators, science clubs, resource persons, and individuals; and inspire them initiate actions to save this fragile abode of ours.

Vinay B. Kamble
Director, Vigyan Prasar
New Delhi

Preface

The planet Earth, our home in the universe, is a large ball of rock spinning through space. It is one of the eight planets that circle the Sun. It is different from the other planets in our solar system. The Earth is the only planet we know that supports life. It is generally believed that the Earth was formed from the collision of many other smaller bodies similar to heavenly bodies, called comets, that elliptically orbit the Sun or asteroids that are still part of the solar system. Depending on the part of the solar gas cloud from which they originated, these were watery, rocky or partly metallic bodies. Because of frequent collisions so much energy was produced that the newly formed proto-Earth melted entirely. Even though ages have passed since then, the interior of the Earth is still very hot. Much of the heat of the Earth's interior comes from those earlier collisions.

After its formation some 4.5 billion years ago, the Earth's internal structure got divided into distinct layers—the core, the mantle and the crust. The interior of the Earth is denser compared to the surface layer called crust. The mantle and the core also differ in terms of their densities. This is because of the gravitational separation of different materials according to their density. The crustal rocks are rich in silicon dioxide. From the analysis of the rocks of the

mantle we know that this region is made up of silicate mineral rich in magnesium and iron. The core is believed to be made of nickel-iron alloys.

During its long history, the Earth passed through an unusual combination of events and processes, which gave it its present form. Gradually the Earth's atmosphere (the blanket of air) and the hydrosphere (comprising of all the waters) developed when gases were removed (a process called de-gassing) from the the core and mantle formed in those early days. Seen from space the Earth appears blue. The colour comes from the water-filled ocean basins that cover most of the Earth's surface. It is generally believed that much of water was brought to the Earth by celestial bodies such as comets.

The Earth is always active, regardless of whether we can sense it or not Its interior is restless. There is no part of Earth that is not continually being subject to change. Generally the changes are very slow, occurring through erosion— movement and disintegration of rocks and minerals by agents such as water, wind and slow movements of great masses of rock called tectonic plates.

But at times there are very rapid and violent changes, caused by events like earthquakes when the Earth's surface undergoes what can be called convulsions or volcanic eruptions when the Earth spews out its molten inner contents.

The movements of the tectonic plates cause earthquakes to release accumulated strain energy, which is transmitted

through the Earth as vibrations called seismic waves. Volcanoes are places where rising molten rocks and hot gases break through the surface of the Earth. These two violent manifestations of an active Earth, capable of causing catastrophic effects, help scientists understand its internal structure. Seismic waves, or waves caused by the Earth's vibrations, are studied to deduce the internal structure of the Earth. The locations of volcanoes and the rocks that they bring out from the interior provide other clues about what lies beneath and also about what is going on inside the Earth.

Earthquakes (occurring under the sea or near the coast) and volcanoes are capable of causing tsunami—a series of killer waves. Earthquakes and volcanoes have been occurring since the Earth came into existence.

This book briefly describes earthquakes, volcanoes and tsunamis—three natural phenomena caused by the violent activities going on inside the Earth. Different concepts and effects related to these phenomena are given in the glossary.

Subodh Mahanti



Earth's Internal Structure

"Everyday experience on the Earth might suggest that our planet is remarkably varied—its materials range from water and ice to atmospheric gases and a host of rocks and minerals. However, the thin surface biosphere we occupy is not typical of the Earth as a whole. Overall, the planet is much less varied—within a few tens of kilometres below the surface, it consists only of rocks, minerals and metallic compounds."

Earth, James F. Luhr (Editor-in-Chief), Dorling Kindersley Limited, London, 2003

We have gathered a lot of information about the various aspects of the Earth's surface. This has been possible because we can make direct observations. We can explore, survey and map the Earth's surface with ease. Scientists have even analysed the rocks. But such direct observations cannot be made with regard to the interior of the Earth. We cannot penetrate the interior for more than a few kilometres. This is an insignificant distance when we consider the fact that the interior extends downwards for more than 6000 kilometres.

As direct observation is not possible, geologists or scientists who study the Earth depend on various indirect evidences. Earthquakes and volcanoes reveal quite a bit of information about the interior of the Earth. Earthquakes often expose deeply buried secrets of the Earth's interiors and volcanoes spew forth contents from deep within the Earth.

The speed of the propagation of the seismic waves varies at different levels of the Earth. Thus measurements of seismic waves passing through the Earth allow scientists to study its interior. The scientists also study the rotation of the Earth and the variation of gravity in different parts of the Earth. They observe the movement of the seas caused by the attraction of the Moon—a phenomenon called the tides.

Scientists have formulated certain theories about the interior of the Earth. So, they also try to recreate the conditions that are supposed to exist in the interior of the Earth. They do this to understand how the interior of the Earth behaves. Based on such studies, scientists have developed a tentative picture of the interior of the Earth. However, the ideas regarding the interior of the Earth are constantly improved as new information is gathered and the previous data is updated.

Some of the conclusions have been proved beyond doubt. For example, that the Earth has a layered structure and that it has a solid inner core can be considered certain. But other theories are still in the process of being refined in the light of new knowledge.

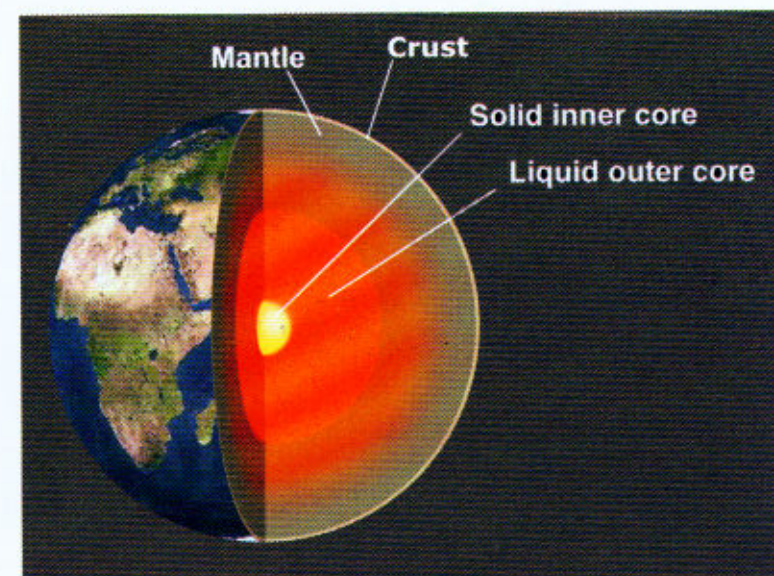
The Layers of Earth

Three primary layers of the Earth, from the exterior going inwards, are:

- Crust,
- Mantle, and
- Core.

The Crust

The outermost layer of the Earth is called the crust. It is the thinnest of the three layers. Its thickness varies from about 30 km below the continents and around 10 km below the oceans. The crust makes up only about 0.5 per cent of the Earth's total mass. The crust of the Earth is composed mainly of basalt and granite. It is cooler and more rigid than the deeper layers.

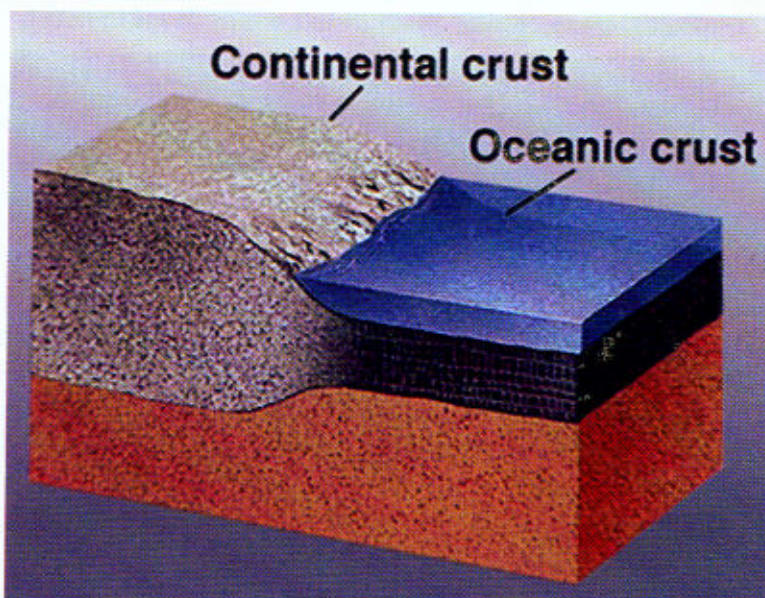


Internal structure of Earth

The crust supports the biosphere, the hydrosphere and the atmosphere. The biosphere is the zone where life naturally occurs. This region extends from the deep crust to the lower atmosphere. The gaseous envelope of air surrounding the Earth to a height of about 1000 km is called the atmosphere. The hydrosphere refers to all the water on the surface of the Earth, including oceans, seas, lakes, glaciers etc.

The crust, which lies on top of the upper mantle, can be subdivided into two main parts—*continental crust* and *oceanic crust*.

The oceanic and continental crusts differ in their composition, density and thickness. The oceanic crust is relatively young. No part of the oceanic crust is more than 200 million years



Continental and oceanic crust

old. Oceanic crust is being continually formed from mantle material within the long rifts known as spreading ridges. The oceanic crust covers about 61 per cent of the Earth's surface but it makes up only about 30 per cent of the mass of the crust.

The Mantle

The Earth's mantle is a thick rocky shell comprising approximately 70 per cent of the Earth's volume. It is the region below the crust and above the core. It has a depth of about

3480 kilometres. The mantle is composed mainly of ferro-magnesium silicates.

Divisions

The mantle can be subdivided into:

- Upper mantle,
- Transition zone and
- Lower mantle.

Upper Mantle

The upper mantle has a density of 3.25 g/cm^3 to 3.40 g/cm^3 and makes up about 10 per cent of the Earth's total mass. The upper mantle has a zone called the low velocity zone. This zone is located at depths of 70 km to 250 km and it is believed to be the zone where most of the magmas or molten material beneath or within the Earth's crust is created.

Transition Zone

The transition zone lies between 400 km to 1000 km below the Earth's surface and it makes up about 17 per cent of the Earth's total mass.

Lower Mantle

The lower mantle comprises of about 41 per cent of the Earth's total mass and lies between 1000 km to 2900 km below the Earth's surface.

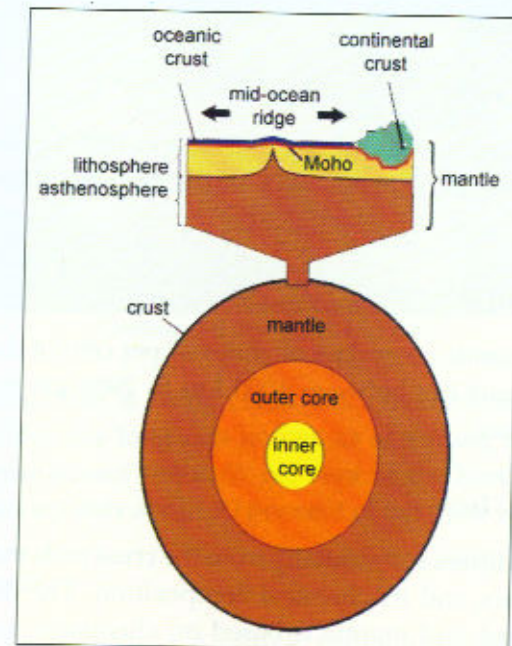
Characteristics

The mantle differs substantially from the crust in its mechanical characteristics and its chemical composition. The distinction between crust and mantle is based on chemistry, rock types and other important characteristics. The mantle has the ability

to move. There are high temperature and pressure gradients between the crust and the core. This leads to development of convection current, which in turn results in a circulation of the Earth's mass—hot molten lava comes out and the cold rock mass goes into the Earth.

Lithosphere

The crust and the upper mantle do not touch each other but together are referred to as lithosphere. The word means "Sphere of Rock". An irregular line called the Mohorovicic discontinuity, separates the crust and the mantle. It is named after the Croatian geophysicist, Andrija Mohorovicic (1857-1936). The Mohorovicic discontinuity, usually called MoHo, marks a sharp and significant change in chemical composition. Therefore it is regarded as a boundary between the crust and the mantle.

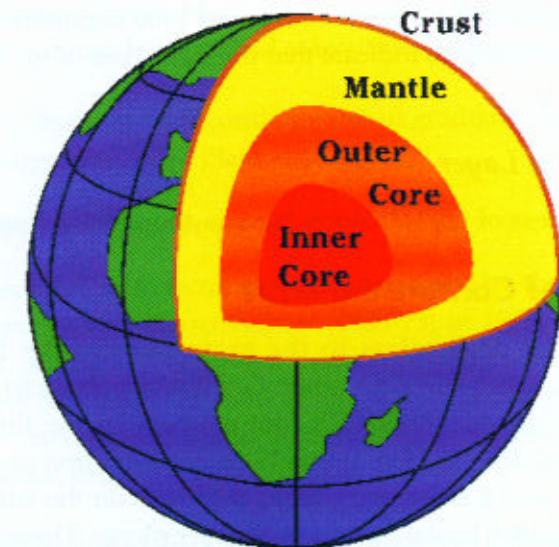


Lithosphere and asthenosphere

The region just lying below the lithosphere is called the asthenosphere or sphere of weakness, where temperatures are high enough to melt rock.

The Core

The outer core is composed mainly of a nickel-iron alloy, while the inner core is almost entirely composed of iron. The Earth's magnetic field is believed to be controlled by the liquid outer core. The total thickness of the Earth's core is approximately 3500 kilometres.



Inner and Outer Core

Divisions

The core consists of three regions:

- Interior core,
- Outer core and
- A transitional layer between the inner core and the outer core.

Outer Core

The outer core has a thickness of more than 1600 kilometres. The outer core is believed to be in a liquid state. In 1987, scientists working at the California Institute of Technology, USA, produced computer-generated maps of the outer core. These maps revealed that the core is not a smooth round surface but contains huge peaks and valleys extending thousands of kilometres horizontally and reaching up to 3 to 10 kilometres vertically.

Inner Core

The thickness of the inner core is about 1300 kilometres. There is strong evidence to indicate that the inner core of the Earth is solid.

Transition Layer

The thickness of the transition layer is about 480 kilometres.

Theory of Continental Drift

Continental drift refers to the movement of the Earth's continents relative to each other. German geophysicist Alfred Lothar Wegener (1880-1930) first enunciated the theory of Continental drift in 1915. It was Wegener, who first suggested that there was a single very large landmass on the surface of the Earth which broke down into smaller pieces. These broken pieces drifted away to form the continents we see today as landmasses separated by oceans.

According to this theory, there was a time (about 225 million years ago) when there was only one single landmass called Panagea. The rest of the Earth's surface was occupied by oceans. Then, some 200 million years ago, Panagea split into two major continents called the Laurasia (which included

what are now North America and Eurasia) and Gondwanaland (which included what are now India, Australia, Africa, South America and Antarctica). Once separated, these two major continents started drifting in different directions over the surface of the Earth. In course of time, these two continents further split into a number of smaller land masses, and continued to move in different directions. In some cases the drifting pieces collided, coalesced and formed large landmasses again.

Wegener's theory gave new directions to investigation in the Earth sciences. His ideas were further refined for a better understanding of earthquakes, volcanic activities, formation of mountains and valleys and many other geological processes.

The hypothesis of continental drift gradually became part of the larger theory of plate tectonics.

Theory of Plate Tectonics

The theory of plate tectonics was formulated by the Canadian geophysicist John Tuzo Wilson (1908-93) in 1965. This is the theory that has been developed to explain the observed evidence for large scale motions of the Earth's lithosphere. The theory encompassed and superseded the older theory of continental drift.

According to this theory, the lithosphere is broken up into what are called tectonic plates. The plates move slowly with respect to each other and with respect to the mantle. It is believed that the plates can move because of the presence of a partly fluid layer beneath them. This layer, called asthenosphere, is not directly beneath the crust but it is believed to be situated near the top of the mantle some 70 to 260 km below the surface. The mantle below the asthenosphere is chemically similar to rock but it has been substantially modified

by heat and pressure and so it is not considered as part of the lithosphere.

Tectonic Plates

There are two types of tectonic plates:

- Continental and
- Oceanic.

There are seven major tectonic plates, namely:

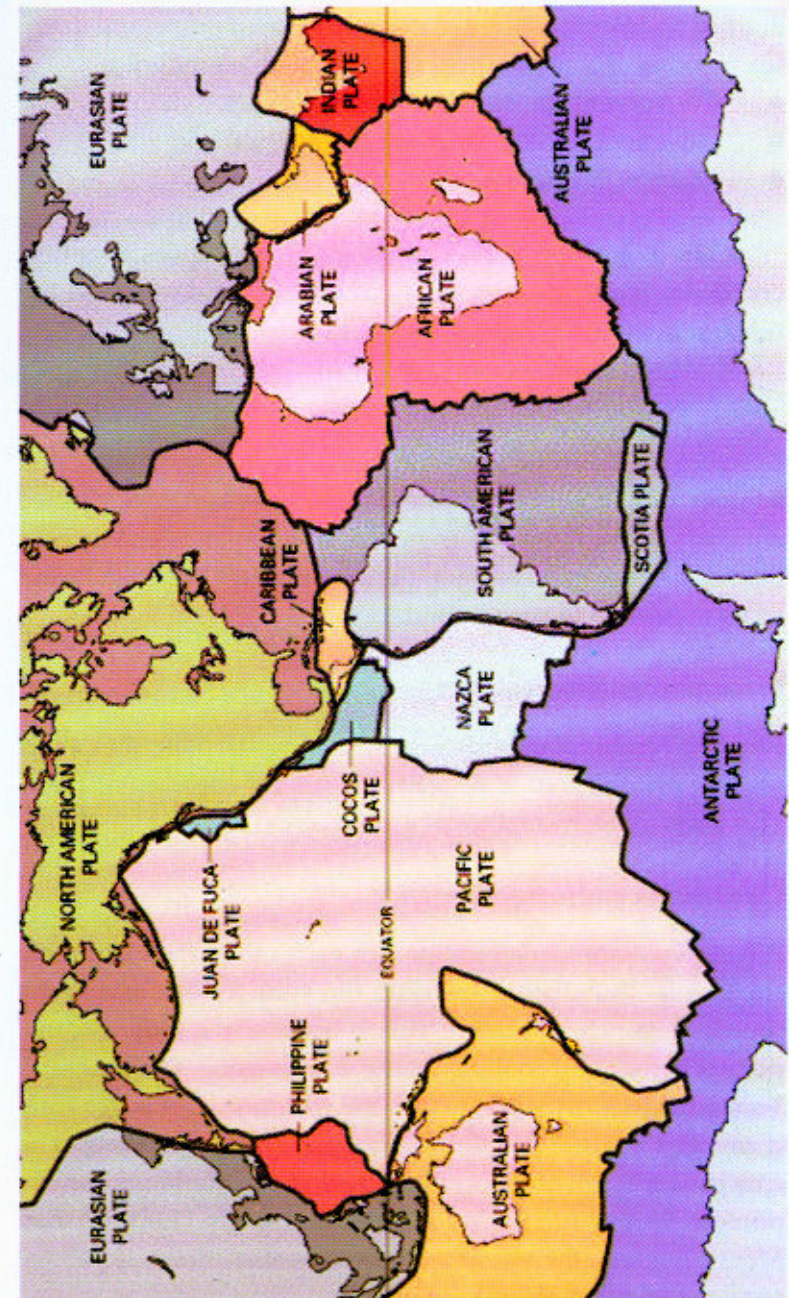
1. Pacific Plate (the largest),
2. African Plate,
3. Eurasian Plate,
4. Australian Plate,
5. North American Plate,
6. Antarctic Plate, and
7. South American Plate.

These seven major plates constitute 94 per cent of the Earth. The remaining 6 per cent is made up of minor plates.

Among the minor plates are:

1. Philippine Plate,
2. Juan De Fuca Plate,
3. Cocos Plate,
4. Caribbean Plate,
5. Nazca Plate,
6. Scotia Plate,
7. Somali Plate,
8. Arabian Plate, and
9. Indian Plate.

The sizes of the plates are not static but constantly changing. Some are expanding while others are getting smaller. The changes take place at the plate boundaries, which are



Map showing major and minor tectonic plates

marked by features such as mountains, ocean ridges and deep-sea trenches. There are three types of plate boundaries:

- Convergent (or destructive) boundaries,
- Divergent (or constructive) boundaries, and
- Transform boundaries.

The convergent and divergent boundaries together constitute 80 per cent of the total plate boundaries and the remaining are transform boundaries.

Convergent Boundaries

Convergent boundaries occur where plates approach one another. Convergent plate boundaries involving oceanic plates are marked by deep sea trenches. But on land, convergent boundaries are marked by mountain ranges. Volcanic island arcs are formed at such boundaries.

Oceanic-continental convergence

When an oceanic plate approaches a continental plate, the denser oceanic plate descends beneath the lighter continental plate. This leads to the formation of a subduction zone.

Oceanic-oceanic convergence

When two oceanic plates approach each other, the older plate sinks or is "subducted" beneath the younger one and in the process a trench is formed. This is because the older oceanic plate is denser and cooler than the younger one. The Marianas Trench, marks the place where the fast-moving Pacific Plate converges against the slower moving Philippine Plate. The Challenger Deep, at the southern end of the Marianas Trench, plunges deeper into the Earth's interior (nearly 11,000 m) than Mount Everest, the world's tallest mountain that rises above sea level (about 8,854 m).

Continental-continental convergence

On land, convergent boundaries are marked by mountain ranges. The Himalayan mountain range demonstrates one of the most visible and spectacular consequences of plate tectonics.

When two continents meet, neither is subducted because the continental rocks are relatively light and, resist downward motion. Instead, the crust tends to buckle and is pushed upward or sideways. The collision of India into Asia 50 million years ago caused the Eurasian Plate to crumple up and override the Indian Plate. After the collision, the slow continuous convergence of the two plates over millions of years pushed up the Himalayas and the Tibetan Plateau to their present heights. Most of this growth occurred during the past 10 million years. The Himalayas, towering as high as 8,854 m above sea level, form the highest continental mountains in the world.

Divergent Boundaries

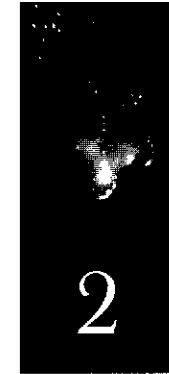
Divergent boundaries occur when plates move away from each other. Such boundaries are marked by slowly spreading rift valleys. When two adjacent plates move away from each other the mantle rises and partially melts to form basaltic magma. The Mid-Atlantic Ridge is an example of divergent boundaries.

Transform Boundaries

The tectonic plates, which carry the continents and the oceans, are moving all the time. They move, albeit very slowly almost imperceptibly, but nevertheless they move, and because of their movement, the continents have drifted around. The movements of the plates also lead to the opening up of new oceans and formation of mountains and volcanoes. The plate boundaries usually occur within oceans or adjacent to continents. Some

plate boundaries occur on land and which are usually marked by mountains or volcanic island arcs.

The San Andreas Fault that runs a length of roughly 1300 kilometres through western and southern California (USA), marks a transform boundary between the Pacific Plate and the North American Plate. All land west of it on the Pacific Plate is moving slowly to the northwest. All land east of it is moving to the southwest under the influence of plate tectonics. The rate of slippage averages approximately 33-37 mm/year across California. While this is an insignificant displacement when measured annually or even in a man's lifetime but imagine the cumulative displacement after a million years and the significance of the bigger picture become clear!



Earthquakes

"Scientists still do not appear to understand sufficiently that all earth sciences must contribute evidence toward unveiling the state of our planet in earlier times, and that the truth of the matter can only be reached by combining all this evidence...It is only by combining the information furnished by all the earth sciences that we can hope to determine 'truth' here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability. Further we have to be prepared always for the possibility that each new discovery, no matter what furnishes it, may modify the conclusion we draw".

Alfred Lothar Wegener in the Origins of Continents and Oceans (1929)

Earthquakes are the shaking of the Earth's surface as a result of the sudden release of the stresses built up in the Earth's crust. Earthquakes are one of the worst natural hazards causing widespread disaster and loss of human lives. Earthquakes usually impact large areas, causing deaths, injuries and destruction on a massive scale. Destruction can be so swift and sudden that people have no time to escape.



Earthquakes are one of the worst natural hazards

In the last two decades of the twentieth century, twenty-six major earthquakes have occurred killing about 1,50,000

people across the globe. It is unfortunate that though they have high consequences, earthquakes cannot be, as yet, predicted with any great degree of success or precision. For this reason the post-disaster response takes place on *ad-hoc* basis.

The branch of science that is concerned with studies of earthquakes is called seismology and the scientists who study earthquakes are called seismologists. The prefix “seismo” comes from the Greek word “*seismos*”, which means earthquakes. Seismologists indicate the size of an earthquake in units of magnitude. There are many different ways of measuring the magnitude.

Almost everyone has experienced at least one of these literally, earth-shaking disasters. Each time an earthquake occurs, it raises a host of questions in our minds. Why do earthquakes occur? Can earthquakes be predicted? Why are earthquakes confined to certain regions of the Earth’s surface? Why do the magnitudes of the earthquakes vary, with some being mild tremors while others are major upheavals? How can the damage be minimised? Can building collapses be prevented? When was the last earthquake? When and where will the next earthquake strike? What do newspapers mean when they talk about the focus or epicentre of an earthquake? Though scientists are yet to fully understand the earthquake processes, they have developed a framework, which provides an explanation for the recurrence patterns of earthquakes across the world. In doing so, they have sought to understand the “whys” and ‘hows’ of earthquakes. They are not the only ones.

Because of their devastating consequences, earthquakes have been the subject of many legends and myths. In the past, different cultures in different times had taken recourse to legends to explain the mystery of the ‘shaking earth’.

Myths, Legends and Beliefs Associated with Earthquakes

In ancient India, it was believed that the Earth was held up by four elephants standing on the back of a turtle. The turtle, in turn was balanced on the head of a snake. When any of these animals moved, the Earth trembled, causing an earthquake. In another version, eight mighty elephants held up the Earth. When any one of these animals got tired, it lowered its head and shook it. This caused an earthquake.



Ancient India, it was believed that the Earth was held up by four elephants standing on the back of a turtle

According to Norse or Scandinavian legends, earthquakes are caused by the violent struggling of the Loki, the god of mischief and discord. Loki was punished because he killed Baldr, the god of beauty and light. Loki was bound tightly and

incarcerated in a cave with a serpent dripping venom on his head. His wife Sigyn stood by him with a bowl to catch the poison so that it did not drip on his face. However, when the bowl is filled to the brim, Sigyn needs to remove it for emptying. That is when the poison drips on Loki's face and he jerks his head away and thrashes against his bonds to avoid the poison. Loki's struggles cause the Earth to tremble.



Loki, the God of mischief and discord

In Greek mythology, the God Zeus struck Earth with a bolt of lightning, as punishment, whenever something evil happened. This causes the Earth tremble.

According to a Japanese legend, earthquakes are caused by a giant catfish called the *manazu*, a wiggly creature living under the Earth.

In 350 BC, the Greek philosopher Aristotle (384-322 BC) proposed the theory that earthquakes were caused by the wind blowing through underground caves. According to the Roman poet Ovid (43 BC-AD 17), earthquakes were caused when the Earth got too close to the Sun. The Earth trembled because of the Sun's amazing radiance.

Today we know that earthquakes are part of a global tectonic process that are beyond the influence or control of humans. We cannot prevent earthquakes. But we can significantly mitigate their effects by identifying hazards, building safer structures and by providing education on earthquake safety. To begin with, it is a good idea to define an earthquake.

What is an earthquake?

An earthquake may be defined as the shaking of the Earth's surface as a result of the sudden release of the stresses built up in the Earth's crust. Earthquakes may range from mild tremors to large-scale earth movements causing extensive damage over a large area.

The point at which the earthquake originates is known as the seismic focus and the point on the Earth's surface directly above this is the epicentre or hypocentre. The location of the epicentre is expressed by defining the latitude and longitude of the place.

During an earthquake one feels a swaying or small jerking motion followed by a small pause, and then a more vigorous rolling or jerking. For small earthquakes the shaking usually lasts only a few seconds. But a major earthquake can make the ground shake for a minute or more. The ground continued to shake for about three minutes during the 1964 Alaska earthquake.

The duration of shaking depends on various factors such as the distance from the epicentre, the condition of the soil and the height of the building and the type of material used for its construction.

How often do earthquakes occur?

Earthquakes are pretty common. It is estimated that approximately once in every 87 seconds somewhere in the world, the Earth shakes slightly. These tremors are strong enough to be felt, but cause no damage. On an average, every year the Earth witnesses 800 earthquakes that pass without causing any damage. In addition to these, every year, there are 18 major earthquakes and one great earthquake.

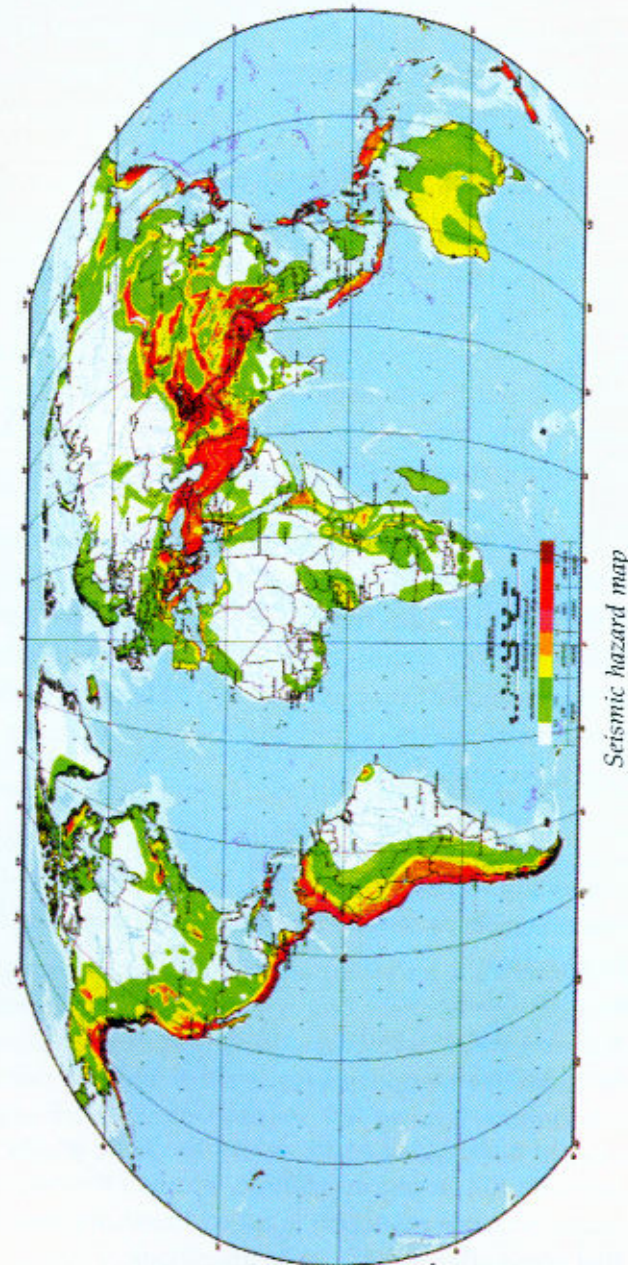
Rarely though, earthquake episodes may be clustered with multiple earthquakes occurring within a short span of time. For example, three severe earthquakes struck New Madrid (USA) within about 7 weeks (16 December, 1811; 07 February and 23 February 1812). On 22 January 1988 three quite severe earthquakes occurred in a span of 12 hours in Tennant Creek, Australia.

A large earthquake is often followed and preceded by tremors of different intensities. To describe this phenomenon seismologists, or scientists who study earthquakes, have coined three terms:

- Foreshock,
- Main shock and
- Aftershock.

In a cluster of earthquakes, the severest one, that is the one with the largest magnitude, is called the main shock. Any quake occurring before it is called foreshock and the quake(s) that come after it is called an aftershock.

GLOBAL SEISMIC HAZARD MAP



Seismic hazard map

Types of Earthquakes

- Earthquakes may be broadly divided into two groups:
- Naturally occurring earthquakes and
 - Human induced earthquakes.

Naturally occurring earthquakes

Naturally occurring earthquakes are also called tectonic earthquakes because they are related to the tectonic nature of the Earth. Most naturally occurring earthquakes occur along a "Fault," which is a fracture or break in the Earth's crust along which movement occurs. Faults may range in length from a few millimetres to thousands of kilometres. Most faults produce repeated displacements over geologic time-frames.

If the movement has a major vertical component, the fault is called a normal fault, where rocks on each side have moved apart. A reverse fault is one where one side has overridden the other. A low angle reverse fault is called a thrust. A lateral fault or tear fault occurs where the relative movement is sideways.

The tectonic earthquakes can be further subdivided into two groups—inter-plate earthquakes and intra-plate earthquakes. When an earthquake occurs along the boundaries of the tectonic plates, it is called inter-plate earthquake. Most of the tectonic earthquakes are of this type.

An intra-plate earthquake occurs within the plate itself and away from the plate boundaries.

Earthquakes occurring in the most stable and older part of the continents are called Stable Continental Region (SCR) earthquakes.

Naturally occurring earthquakes may also be caused by the movement of magma in volcanoes. Such earthquakes serve as an early warning of volcanic eruptions.

Human-induced earthquakes

Earthquakes may be induced by human activities. These activities include removal or injection of fluids into deep wells for waste disposal and secondary recovery of oil; build-up of large mass of water behind dams; massive explosions, such as nuclear explosions; and collapse of large buildings.

The earthquake that occurred at Koyna, Maharashtra in 1967 was one of the largest earthquakes induced by an artificial reservoir. One of the most well-known human-activity-induced earthquakes resulted because of fluid injection at the Rocky Mountain Arsenal near Denver (USA) in 1967.

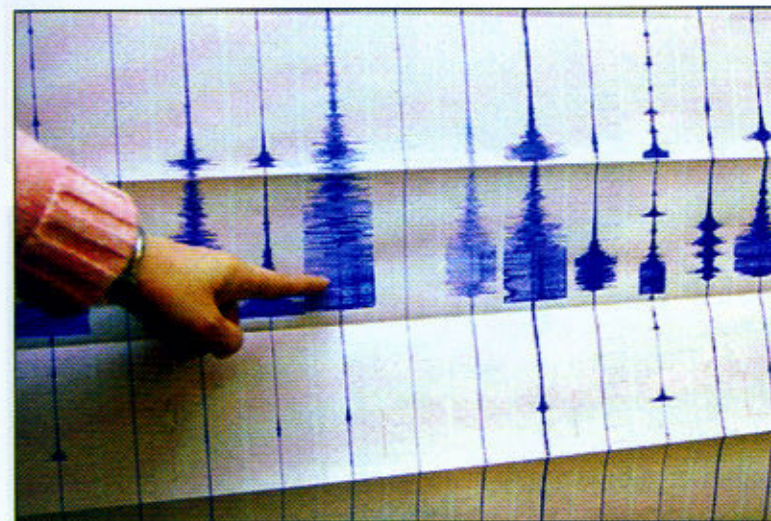
What causes an Earthquake?

According to plate tectonics theory the Earth's crust is regarded as a jigsaw of rigid major and minor plates up to hundreds of kilometres thick, which move relative to each other, probably under the influence of convection currents in the mantle below. The globe is divided into a number of seismic plates. Major landforms occur at margins of the plates where the plates are colliding or moving apart. The plates move very slowly and sometimes slide past each other. Most severe earthquakes occur when the plates meet. Sometimes the edges of the plates grip each other and cannot move, so pressure builds up. Suddenly the plates slip and lurch past each other making the land shake violently. In the process the Earth's crust gets ruptured causing huge faults.

Once faults are formed these become areas of weakness. Earthquakes are means of releasing energy to remove accumulated strain are mostly confined to the existing faults. New faults are caused when the strain is released at places away from the existing ones.

How do we know how powerful an Earthquake is?

Magnitude and Intensity are two ways of measuring an earthquake. The magnitude of an earthquake is measured on the basis of the ground wave recorded by the seismograph—the instrument that is used to detect earthquakes. The strength of an earthquake is measured on the basis of the maximum amplitude of the signal recorded by a seismograph and how far the instrument is stationed from the earthquake.



Graph showing different intensity of Earthquake

Measuring Magnitude

The magnitude on the Richter scale is a measure of the seismic energy radiated by an earthquake. The Richter scale, named after the US physicist Charles F. Richter of the California Institute of Technology was first introduced in 1935. Richter evolved the scale from patterns he discovered by studying hundreds of earthquakes.

The Richter Scale

The classification of earthquakes based on the magnitude on the Richter scale is given below:

Less than 2.0	Generally not felt, but recorded
2.0-2.9	Potentially perceptible
3.0-3.9	Felt by some
4.0-4.9	Felt by most
5.0-5.9	Damaging shocks
6.0-6.9	Destructive in populated regions
7.0-7.9	Major earthquakes; inflict serious damages
Greater than 8.0	Great earthquakes; cause extensive destruction near epicentre

The Richter scale starts at one end has no upper limit. The Richter scale has a logarithmic basis, so each unit is 10 times greater than the one before. The Richter scale does not measure an earthquake's effects. It gives the measure of its strength in terms of the energy released as measured by seismograph.

The earthquake of highest magnitude till date in India is of 8.7 on the Richter scale, which was recorded in the Shillong Plateau on June 12, 1897. Richter magnitude's effects are confined to the vicinity of the epicentre. The largest known shocks have had magnitudes in the range of 8.8 to 8.9.



Charles F. Richter

Earthquake Intensity

Intensity is the measurement of the size of an earthquake based on its impacts on people, objects, buildings and land. The intensity of an earthquake at a particular locality is a measure of the violence of the Earth's movement as produced there by the earthquake. It is determined from reported effects of the tremor on human beings, furniture, buildings, and changes to natural surroundings etc. Unlike the magnitude which has a



Intensity of Earthquake is determined from reported effects of the tremor on human beings, furniture, buildings, and changes to natural surroundings, etc.

unique value for a particular earthquake, the intensity of an earthquake at a place depends on the distance of that place from the epicentre, the depth of the focus, the intervening and local earth structures and the type of fault motion that caused the earthquake.

The 12-point graded Modified Mercalli Intensity scale is widely used for measuring intensity. The Mercalli scale was

originally developed by Italian seismologist Giuseppe Mercalli in 1902. The Mercalli's scale noted the observed effects of an earthquake on people and property. In 1931, American seismologists Harry Wood and Frank Neumann developed the Modified Mercalli scale. The Modified Mercalli scale assigns Roman Numerals from I to XII to measure the intensity of the earthquake.

The Modified Mercalli Scale

- I. Not felt except by a very few.
- II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
- III. Quite noticeably felt by those indoors, especially by those on upper floors of buildings. Vibration feels like that of a truck passing by. Standing cars may rock slightly.
- IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing cars rock noticeably.
- V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of tall objects sometimes noticed. Pendulum clocks may stop.
- VI. Felt by all; many run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
- VII. Everybody runs outdoors. Damage negligible in constructions of good design but considerable in poorly built or badly designed structures. Some chimneys broken. Car drivers take notice.

- VIII. Damage slight in specially designed structures; considerable in ordinary buildings, great in poorly-built structures. Columns, monuments, walls may fall. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Car drivers are disturbed.
- IX. Damage considerable even in specially designed structures; Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
- X. Most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Water splashes over banks.
- XI. Few, if any masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
- XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

An earthquake measuring 12 on the Mercalli scale would create new topography by forming new lakes, huge falls of rocks and major earthquakes.

The most devastating earthquake in recorded history was in China's Shaanxi province in 1556. It is likely to have measured nine on the scale and it killed 830,000 people.

MSK Scale

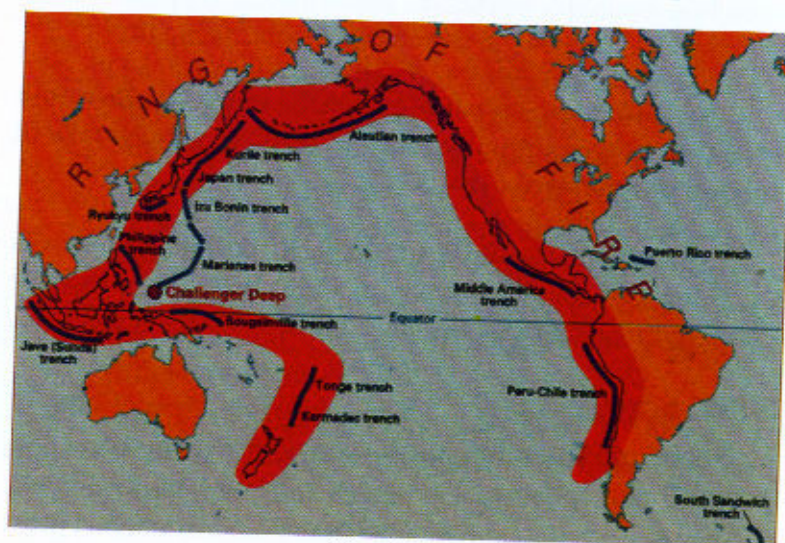
The Medvedev-Sponheuer-Karnik (MSK) scale of seismic intensity was widely used in Europe and India starting in 1964. This scale also has a similar range from Roman numeral I (least perceived) to XII (most severe).

The basic difference between magnitude and intensity needs to be clearly understood. Magnitude is the measure of the size of an earthquake arrived at by the amount of strain energy released by the fault rupture. There will be only a single value for the magnitude of a given earthquake. Intensity is a measure of the severity of shaking generated at a given location. It is obvious that the severity of shaking is much higher near the origin or the epicentre of the earthquake than it is farther away. So during a particular earthquake of a certain magnitude different locations would experience different levels of intensity.

Are there Earthquake-prone Zones?

Earthquake can strike any location at any time. But most of the world's earthquakes take place in the horseshoe-shaped zone called the circum-Pacific seismic belt. This zone, also called the "Pacific Ring of Fire" or "Ring of Fire," is 40,000 km long.

Scientists have identified three large zones of the Earth where earthquakes are more frequent than in other places.



Ring of Fire

Zone I

The first zone is the circum-Pacific Seismic belt, the world's, greatest earthquake belt where about 81 percent of the world's largest earthquakes occur. The belt, which is found along the rim of the Pacific Ocean, extends from Chile, northward along the South American coast through Central America, Mexico, the West Coast of the USA and the southern part of Alaska, through the Aleutian islands to Japan, the Philippine Islands, New Guinea, the Island group of the southwest Pacific, and to New Zealand.

Zone II

The second important belt, the Alpide, accounts for about 17 percent of the world's largest earthquakes. It extends from Java to Sumatra, through the Himalayas, the Mediterranean and out into the Atlantic. It is the second most seismic region in the world.

Zone III

The third important belt follows the submerged mid-Atlantic Ridge.

How are Earthquakes Measured?

The instrument that records the shaking of the Earth is called seismograph. The earliest device for detecting earthquake was invented by the Chinese philosopher Chang Heng in 132 AD. The device was a large urn with eight dragon heads on its outside facing—North, South, East, West, Northeast, Southeast, Northwest and Southwest- the eight principal directions of the compass. The urn was attached to a base. Below each dragon-head was a toad with its open mouth pointed towards the dragon. In the event of an earthquake one or more of the eight dragon-mouths would release a ball into the open mouth of



The earliest device for detecting earthquake

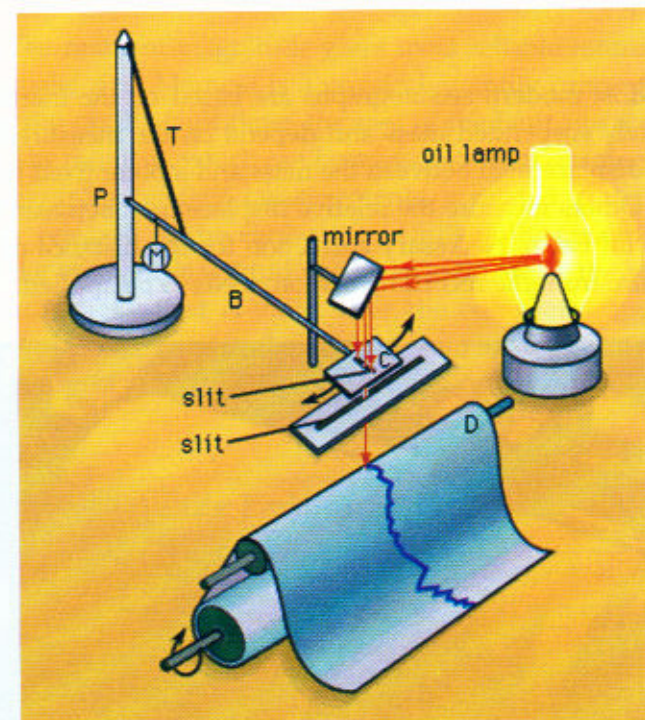
the toad sitting below. The direction of the shaking could be determined by noting which of the dragons had released the ball.

The modern seismograph was invented in Japan around 1880 AD by John Milne (1850-1913), who was a professor of geology and mining at the Imperial College of Engineering, Tokyo. It was a compact device that could be installed in various locations around the globe. These



John Milne

instruments helped to gather the earliest data on geographic distribution of earthquakes. A typical seismograph has three components—the sensor, the recorder and the timer.



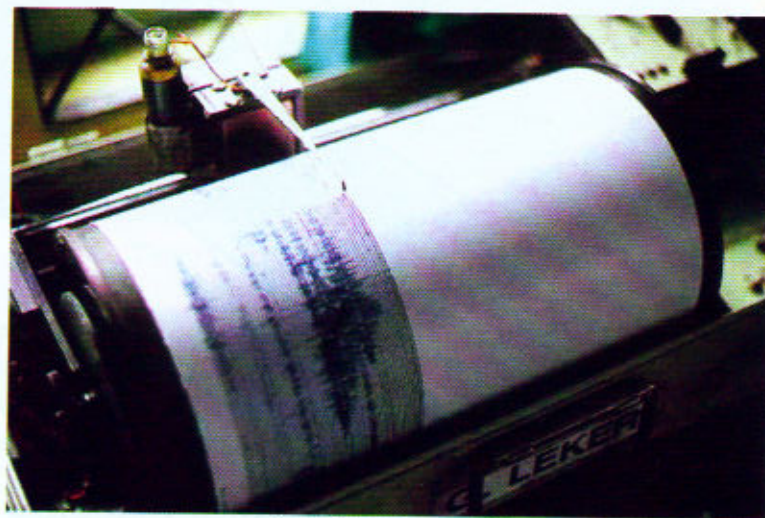
Horizontal pendulum seismograph, was invented by seismologist John Milne in 1880

A seismogram is the record produced by seismographs that is used to calculate the location and magnitude of an earthquake. On a seismogram, the horizontal axis represents time measured in seconds and the vertical axis represents the ground displacement, usually measured in millimetres.

The movement of a seismometer can be converted into a seismogram in several ways viz., a pen drawing on ink line on paper revolving on a drum; a light beam making a trace on a

moving photographic film and electromagnetic system generating a current that electronically records on tape. In the absence of an earthquake the seismogram is just a straight line except for small wriggles caused by local disturbance or noise etc.

Most modern seismographs are based on the inertia of delicately suspended mass and depend on the measurement of the displacement between the mass and a point fixed to the earth. Others measure the relative displacement between two points on Earth. Necessary correction for the distance of the epicentre from the recording station needs to be applied.



A modern seismograph

Since Richter's method for measuring the magnitude was strictly valid only for certain frequency and distance ranges it is not suited to accurately measure earthquakes with magnitude over approximately 6.8. So to take advantage of the growing number of globally distributed seismograph stations, new magnitude scales like body-wave magnitude (Mb), surface

wave magnitude (Ms) and moment magnitude (Mw) were developed. These scales were basically extensions of the original idea developed by Richter.

The moment magnitude gives most reliable estimate of earthquake size. Moment is a physical quantity proportional to the slip on the fault times the area of the fault surface that slips. The moment, which can be measured from seismograms and also from geodetic measurements, is related to the total energy released in the earthquake. Unlike other magnitude scale the moment magnitude gives an estimate of the size of the earthquake that is valid over the complete range of magnitudes. The magnitude scales have no upper or limit. The magnitude of very small earthquake can be zero or even negative.

Worldwide Earthquake Frequency

Description	Magnitude	Average Annual Occurrence
Great	8 and above	1
Major	7-7.9	18
Strong	6-6.9	120
Moderate	5-5.9	800
Light	4-4.9	6200 (estimated)
Minor	3-3.9	49000 (estimated)

Benno Gutenberg and Charles Francis Richter published their monograph, *The Seismicity of the Earth*, in 1954. This was the first comprehensive world-wide catalogue of instrumentally located earthquakes. In Gutenberg and Richter's catalogue, the first instrumentally located earthquake in the Indian region was the great Kangra earthquake of 04 April 1904.

The Gutenberg-Richter law expresses the relationship between the magnitude and total number of earthquakes in any given region and time period.

Seismic maps

Seismologists have developed special maps showing the extent of various levels of seismic effects within a particular region or locality. Such maps are called iso-seismal maps. Such maps outline areas of equal value in terms of various seismic effects



Seismic Zone of India

like ground shaking intensity, shaking amplification etc. These maps can also be called seismic hazard maps. In building codes, areas are converted into seismic zone maps for using for seismic analysis of structural components of buildings. Such maps describe seismic hazards as zones at different risk levels.

Seismic Zones: India

India has been divided into five different seismic zones. These are classified as V to I with respect to the severity of the earthquake on a decreasing scale where:

- Zone I means no risk
- Zone II means low risk
- Zone III means moderate risk
- Zone IV means high risk and
- Zone V means very high risk

A catalogue prepared by the India Meteorological Department has listed about 1200 earthquakes documented in India.

Seismic waves

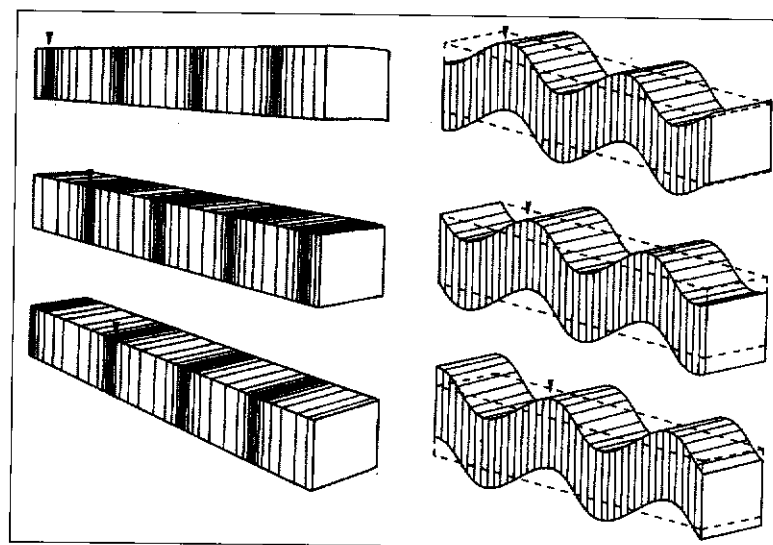
An earthquake releases large amount of strain energy in the form of vibrations called seismic waves propagating within the Earth or along its surface. Seismic waves can be felt around the globe. The physics of seismic waves is rather complex. These waves move in all directions and they reflect and refract at each interface. The waves, which pass through the body of Earth, are called body waves. Those waves, which are restricted to near the Earth's surface, are called surface waves.

There are two types of body waves—Primary waves or P-waves and Secondary waves or S-waves. Surface waves consist of Love waves and Rayleigh waves. The P-waves are

the fastest and they are followed by S-waves, Love waves and Rayleigh waves.

The P-waves impart a back-and-forth motion to rock particles along their path. The P-waves are the first ones we feel.

S-waves (also called transverse body waves) shake the rocks up and down and from side to side. S-waves do not travel through liquids.



S and P Waves

Once P- and S-waves reach the surface, most of their energy is reflected back to the interior of the Earth. Some of this energy again comes back to the surface by reflections at different layers of rock and soil.

Rayleigh waves were named after Lord Rayleigh (1842-1919), who predicted their existence. These waves travel over the surface giving an elliptical motion to rock particles.

Love waves named after Augustus Edward Hough Love (1863-1940) displace particles perpendicularly to the direction of propagation and have no longitudinal or vertical component.

P-waves are the first to cause vibration of a building. After P-waves, come the S-waves, which cause structure to vibrate from side to side. As buildings are more easily damaged from horizontal motion rather than from vertical motion, S-waves are the most damaging ones. Rayleigh and Love waves arrive last. While P- and S-waves mainly cause high frequency vibrations, Rayleigh and Love waves cause low frequency vibrations. Being short and fast, P- and S-waves create jerks and jolts. Surface waves are long and slow and they create rolling effects. Seismic waves travel at different speeds in different types of rocks. Surface waves stay longer but the body waves die out quickly.

Earthquake Damage

The earthquakes having the same magnitude on the Richter scale may vary in the damage they leave behind. This is because the extent of damage depends on more than one factor. The depth of the focus may be one such factor. If an earthquake is very deep, surface damage caused by it may be little. The earthquake that struck Gujarat, India, on 26 January 2001 was relatively shallow; less than 25 Km deep. The earthquake in Garhwal, India in March 1999 was also shallow.

Effects of earthquakes

Sensitive seismographs detect earthquakes occurring in different parts of the world everyday. Luckily most of these are minor and cause no damage.

An earthquake shakes the ground in all three directions—along the two horizontal directions and the vertical direction.

The ground also shakes randomly back and forth along each of the three directions. Horizontal shaking is the most damaging. Damage by earthquake primarily occurs due to collapse of structures or buildings.



Damage caused by Earthquake in India

- Damage during an earthquake depends primarily on:
- **Strength of shaking.** This decreases rapidly with distance from the earthquake. The strong shaking along the fault segment that slips during an earthquake becomes half as strong at a distance of about 13 km, a quarter as strong at a distance of 27 km, an eighth as strong at a distance of 48 km, and a sixteenth as strong at a distance of 80 km.
 - **Length of shaking.** Length of shaking depends on how the fault breaks during the earthquake. The longer buildings shake, the greater the damage that they sustain.
 - **Type of soil.** Shaking is increased in soft, thick, wet soils.
 - **Type of building.** Certain buildings are not resistant enough to the side-to-side shaking common during earthquakes

Damage and loss of life during an earthquake are also greatly increased because of falling structures and flying glass and objects. Flexible structures built on bedrock are generally more resistant to earthquake damage than rigid structures built on loose soil. In certain areas, an earthquake can trigger mudslides, which slip down mountain slopes and can bury habitations. Large earthquakes cause violent motions on the Earth's surface. Sometimes they trigger a monstrous series of sea waves, which sweep up on land and add to the general destruction. Such waves often occur in the Pacific Ocean. These destructive waves are called tsunamis.

Minimising Damage

The message that the damage can be substantially minimised by incorporating proper safety measures is a simple one. But it is one that is easily forgot and apparently needs to be learnt afresh each time a disaster strikes. It is then that the need to enact proper laws to make earthquake safety norms binding on buildings is highlighted.

Codes and guidelines for earthquake resistant building were first developed by the Bureau of Indian Standards in 1962 and then again, in 1967. Subsequently these were revised, updated and expanded. However, the code is only recommendatory in nature. So its implementation has not been satisfactory (perhaps with the exception of some government organisations). There is little doubt that legislations should include amendment to the Town and Country Planning Act, Master plan development rules, and empowerment of Development Authority to exercise necessary control and incorporation of safety requirements in building bylaws of local bodies.

Fatalities can be reduced if timely and efficient relief work is organised. This requires heavy equipment such as cranes to



The damage caused by Earthquake that struck Gujrat (India) on January 26, 2001

shift rubble, smaller items such as blowtorches to cut through obstacles, acoustic devices and sniffer dogs to locate people buried under rubble, doctors, particularly orthopaedic surgeons, equipped with adequate medical facilities including blood supplies for emergency transfusions. Temporary shelters, blankets and food would also be needed. For managing the post-disaster scenario we require to place more emphasis on the following:

- Extensive public awareness campaigns, especially in rural areas.
- Greater involvement of NGOs and private sectors.
- Effective communication system.

Recent experiences have demonstrated the utility of Amateur or Ham Radio in establishing contacts with the affected area when normal communication network breaks down. Since amateur radio operators can establish wireless communications to support communities with emergency and disaster communications, efforts ought to be made to popularise Ham Radio. The Internet can help make relevant information available without any time lag. It can also considerably aid communications.

Engineers have developed norms for making earthquake-resistant buildings. The idea is not to make totally earthquake-proof building but to enable buildings to resist the effects of the quake. These buildings have good structural configuration, lateral strength, adequate stiffness and good ductility.

Such earthquake-resistant buildings would not collapse even if severely damaged.

Predicting Earthquakes

It is agreed that a valid prediction should have the following four components:

1. The period within which the event will occur.
2. Location of the event.
3. Magnitude range.
4. Statistical probability of the event

The following developments in the second half of the 20th century helped major advances in seismology:

- The establishment of a network of 120 seismic stations by the US Government in the 1960s.
- The development of the theory of plate tectonics, which helped to develop a framework for understanding the basic dynamics of earthquakes.

- The development of computer technology that made it possible to analyse large amount of data.

It seems logical to expect that with such large amounts of data flowing in, it would become easy to predict earthquake occurrences. However, this is not the case. The reason is that despite these significant developments, many gaps exist in our understanding of earthquake processes even for those locations from where extensive data is available. Of course, there have been a few isolated cases of success.

The 1971 Blue Mountain Lake earthquake in New York was successfully predicted, as was the Heicheng earthquake in 1975. But then again, the prediction for the Parkfield earthquake proved to be wrong. Currently there is no scientifically established procedure for accurate prediction of earthquakes.

Some experts tend to believe that precise earthquake predictions within narrow limits of time, location and magnitude may not be ever possible because of the complex and unreliable factors involved. This is in spite of the fact that earthquakes show a marked spatial distribution—the vast majority are located within narrow zones, which correspond to the boundaries of the crustal plates. Of course, there are statistical techniques that can be used, to approximately predict when and where an earthquake will take place, if all the necessary data are available. But then prediction based on such methods are vague—the location can be anywhere within 200 km of a point and the time limit is up to 10 years. So such predictions, even if proved to be right, are useless for disaster preparedness.

While earthquakes cannot be stopped or accurately predicted it is possible to design structures, which can safely negotiate and even resist the motions of the ground. Today,

earthquake-resistant design of structures has grown into a multi disciplinary field of engineering.

Earthquakes in India

India has had a long history of recorded earthquakes. However, there is one that is still etched in public memory because it changed a day of national rejoicing into sorrow that enveloped the entire country. The earthquake happened on 26 January 2001 at 8:46:41 IST. It struck at the area coordinates of latitude of 23.40, longitude 70.32 and occurred at a depth of 23.6 km. The earthquake that suddenly struck western Gujarat when the President was saluting the Republic on its 51st anniversary changed the joyous mood of the nation into one of sorrow.

According to India Meteorological Department, the Republic Day (2001) earthquake registered 6.9 on the Richter scale. But the US Geological Survey put its magnitude at 7.9. There were at least 83 aftershocks in the ten hours following the major quake. Several of the aftershocks registered magnitudes of 5 or 6 themselves. The epicentre was near the desert town of Bhuj in Gujarat. The earthquake, close to the border with Pakistan, caused high-rise buildings to sway far away in the capital, New Delhi and was as felt as far away as in Nepal and in Bangladesh. Some experts compared the magnitude of this earthquake to the detonation of 60 megaton hydrogen bomb. It was the most powerful to strike India since 15 August 1950 when an 8.5 magnitude earthquake killed 11,538 people in Assam.

In 1897, a severe (magnitude 8.7) earthquake had occurred in the Shillong plateau. These two earthquakes were so intense that ground elevation changed permanently and stones were thrown upward. What is more is that even rivers changed their courses. The 1819 Runn of Kutch earthquake is considered to



Picture showing damage caused by various Earthquake in India

be one of the largest intra-plate earthquake in the world. It resulted in a surface rupture above 100 km long. The Latur (Killari) earthquake on 30 September 1993 was the most devastating Stable Continental Range earthquake in the world. The epicentre of the Latur earthquake was located in a region considered not to be seismic (aseismic) in nature. The earthquake led to rethinking of seismic hazard assessment in peninsular India.

A large part of India is vulnerable to earthquakes of varying intensities. Earthquakes in India are caused as a

Table: List Major Earthquakes in India

Date	Epicentre	Magnitude
16 June 1819	Kutch, Gujarat	8.0
10 January 1869	Near Cachar, Assam	7.5
30 May 1885	Sopor, Jammu&Kashmir	7.0
12 June 1897	Shillong plateau	8.7
08 February 1900	Coimbatore	6.0
04 April 1905	Kangra, Himachal Pradesh	8.0
08 July 1918	Srimangal, Assam	7.6
02 July 1930	Dhubo, Assam	7.1
15 January 1934	Bihar Nepal Border	8.3
26 June 1941	Andaman Islands	8.1
23 October 1943	Assam	7.2
15 August 1950	Assam	8.5
21 July 1956	Anjar, Gujarat	7.0
10 December 1957	Koyna, Maharashtra	6.5
19 January 1975	Kirnaur, Himachal Pradesh	6.2
06 August 1988	Manipur- Myanmar Border	6.6
21 August 1988	Bihar-Nepal Border	6.4
20 October 1991	Uttarkashi	6.6
30 September 1993	Latur -(Latur), Maharashtra	6.3
22 May 1997	Jabalpur, Madhya Pradesh	6.0
29 March 1999	Chamoli, Uttarakhand	6.8
26 January 2001	Bhuj, Gujarat	7.8

result of the collision between the Indian plate and the Eurasian plate. The most intense earthquakes occur on the boundaries of the Indian plate to the east, north and west. The Himalaya mountain range is the result of the collision of Indian and Eurasian plates, which took place about 40 million years ago.

The Indian plate is continuing to penetrate deeper at the estimated rate of 5 centimetres a year. Several large earthquakes have occurred in the Himalayan collision zone. This zone, marked by intense seismic activity, has witnessed four great earthquakes in the brief period of 53 years, namely:

- The 1897 Assam earthquake;
- The 1905 Kangra earthquake;
- The 1934 Bihar-Nepal earthquake and
- The 1950 Assam earthquake.

It is very likely that great earthquakes will occur in this region in the future too.

Two premier government organisations viz., India Meteorological Department (IMD) and Geological Survey of India (GSI) are primarily responsible for monitoring the earthquake hazard in the country. The IMD is the national agency for detecting and locating earthquakes and for the evaluation of seismicity in different parts of the country.

The first seismological observatory in India was established in Alipur (Kolkata) in 1898. In 1899, observatories were established at Mumbai and Chennai. The Chennai observatory was later shifted to Kodaikanal. The national network of seismological observatories was further expanded and upgraded by the India Meteorological Department. Today India has observatories all over the country.

Dos and Don'ts during and after an Earthquake

It is important to remember that an earthquake, by itself, does not hurt or kill people. People are hurt or killed by falling plaster, collapsing walls or falling objects. There are other associated dangers. There may be short circuits and electric fires caused by falling debris and vibrations. Fires may also be caused by lighted gas or stoves.

It is important to keep the following Do's and Don'ts in mind both during and after an earthquake.

DURING AN EARTHQUAKE

If you are inside a house:

- Do not panic.
- Stay inside the house.
- Reach the nearest safe place. Take cover. Hold on to a firm support like heavy furniture or stand against an inside wall.
- Do not rush outside till the shaking is over. It is quite possible that doors or staircases may be broken or damaged.
- Do not use elevators or lifts.
- Do not shelter near glass windows, doors, almirahs, mirrors etc.
- If you happen to be in bed, stay there. Protect your head with a pillow. Hold on firmly to the bed.

If you are in an open place:

- Go to a clear spot away from buildings, trees, power lines etc.
- Running through streets may be dangerous because hoardings or lamps may fall on you.
- Drop to the ground and lie there till the quaking stops.

If you are driving

- Park in a clear place away from buildings, trees and power lines.
- Never stop at overpasses, underpasses or bridges.
- Turn off ignition.
- Stay inside the car, the hard-topped vehicle provides protection from flying or falling objects.

After An Earthquake

- Evacuate if the house appears unsafe.
- Be prepared for aftershocks.
- Check if anyone is hurt. Do not attempt to move the seriously injured ones. Wait for medical help to arrive.
- Do not crowd the street. This may hamper emergency services.
- Do not encourage or indulge in rumour mongering.
- Switch off all electrical appliances. Turn off the electricity at the main fuse box or circuit breaker if you see sparks or broken or frayed wires, or if you smell hot insulation.
- Look for and extinguish small fires.
- Disconnect cooking gas connections.
- Protect your feet by wearing shoes.
- Try to listen to a battery operated radio or television for the latest emergency information.
- Ensure that water is not unnecessarily wasted because it might be required for fire fighting.

Earthquake -preparedness

It helps to have a contingency plan if you live in an earthquake-prone area.

- All family members should know how to turn off gas, water, and electricity mains
- Rehearse family emergency procedures

- Assemble a survival kit containing:
 - Non-perishable food items.
 - Drinking water
 - First aid kit and manual
 - Fire extinguisher
 - Blanket
 - Sealable plastic bags
 - Torches with spare fresh batteries and bulb
 - Critical medication, extra spectacles
 - Tools-screwdriver, pliers, wire, knife
 - Short rubber hose
 - Pre-moistened tissues
 - Feminine supplies
- Make plans for reuniting your family if ever separated by disaster.
- Know emergency telephone numbers (doctor, hospital, police, etc)
- Anchor heavy objects (bookcases, wall units, mirrors, cabinets, etc.) to walls
- Never place heavy objects over beds
- Keep heavy objects lower than head height of shortest member of family.

Tips for volunteers

If volunteering to do relief work in a post-earthquake scenario, remember to carry:

- Battery-powered torches, AM/FM radio,
- Spare batteries
- Extra change of clothes,
- Sturdy shoes with thick soles
- Extra prescription medicines,
- Complete first-aid kit,
- Candles and matches in waterproof containers
- Fresh drinking water or chlorine drops for sterilising drinking water

- Dry or canned foods
- Paper plates, plastic utensils, cups
- Blankets and bedding
- Toothbrushes, toothpaste, antibacterial soap, work gloves etc
- List of important phone numbers,
- Stove, fuel, tent, sleeping bags, fire extinguisher, rain gear

Being prepared is the key word to facing an emergency. Since most earthquakes strike without warning, it pays rich dividends to plan for such a contingency and to have adequate plans in place.

Some Major Earthquakes Worldwide			
Date	Location	Estimated deaths	Richter magnitude
AD 856	Corinth, Greece	45,000	—
22 December 856	Damghan, Iran	200,000	—
23 March 893	Ardabil, Iran	150,000	—
09 August 1138	Aleppo, Syria	230,000	—
September 1290	Chihli, China	100,000	—
23 January 1556	Shansi, China	830,000	—
30 December 1730	Hokkaido Island, Japan	137,000	—
1731	Beijing, China	100,000	—
11 October 1737	Kolkata, India	300,000	—
01 November 1755	Lisbon, Portugal	700,000	8.7
16 December 1811	New Madrid, Missouri, USA	<10	7.7
24 December 1854	Toki, Japan	3,000	8.4
31 August 1886	Charleston, South, Carolina, USA	60	7.6
04 April 1905	Kangra, India	19,000	8.6
18 April 1906	San Francisco, California, USA	3000	7.7

Date	Location	Estimated deaths	Richter magnitude
31 January 1906	Pacific Ocean off the coast of Ecuador	15,000	8.8
17 August 1906	Santiago, Chile	20,000	8.6
1907	Tajikistan	40,000	—
28 December 1908	Messina, Sicily, Italy	75,000	7.5
13 January 1916	Avezzano, Italy	29,980	7.5
16 December 1920	Gansu, China	2,00,000	8.6
03 February 1923	Kamchatak, Peninsula, Russia	—	8.5
01 September 1923	Kwanto, Japan	143,000	8.3
07 March 1927	Tango, Japan	3,020	7.9
22 May 1927	Near Xining, China	2,00,000	8.3
25 December 1932	Jansu, China	70,000	7.6
02 March 1933	Sanriku, Japan	2,990	8.9
15 January 1934	Bihar, India and Nepal	10,700	8.4
30 May 1935	Quetta, now in Pakistan	50,000	7.5
01 February 1938	Banda Sea, Indonesia	—	8.5
25 January 1939	Chillan, Chile	30,000	8.3
27 December 1939	Erzincan, Turkey	30,000	8.0
01 April 1946	Unimak Island, Alaska	165	7.3
05 October 1948	Ashgavat, Turkmenistan	1,10,000	7.3
05 August 1949	Pelileo, Ecuador	6000	6.8
15 August 1950	Assam, India and Bordering China	1530	8.7
04 November 1952	Kamchatka Peninsula, Russia	0	9.0
09 March 1957	Andreanof Island, Aleutian Island, Alaska	0	9.1
29 February 1960	Agadir, Morocco	12,000	5.9
21-30 May 1960	Chile	5700	9.5
01 September 1962	Iran	12230	7.3
13 October 1963	Kuril Island, Japan and Russia	—	8.5
28 March 1964	Prince William Sound, Alaska	125	9.2
04 February 1965	Rat Islands, Aleutian Islands, Alaska, USA	0	8.7

Date	Location	Estimated deaths	Richter magnitude
19 August 1966	Eastern, Turkey	2,520	7.1
31 August 1968	Khurasan, Iran	12,000	7.3
25 July 1969	China (Eastern part)	3,000	5.9
05 January 1970	Yunnan Province, China	10,000	7.5
31 May 1970	Yungay, Ranrahirca, and Huaras, Peru	66,000	7.8
10 April 1972	Ghir, Iran	5,054	7.1
23 Decemer 1972	Managua, Nicaragua	5,000	6.2
28 December 1974	Pakistan	5,300	6.2
04February 1975	Liaoning Province, China	10,000	7.4
06 September 1975	Lice, Turkey	2,300	6.7
04 February 1976	Guatemala City, Guatemala	23,000	7.5
25 June 1976	New Guinea and Irian Jaya	8,000+	7.1
27 July 1976	Tangshan, China;	655,000	8.0
16 August 1976	Philippine island of Mindanao	8,000	7.9
24 November 1976	Turkey (Eastern part)	5,000	7.3
16 September 1978	Iran (Eastern part)	15,000	7.8
10 October 1980	Algeria (North-western part)	3,500	7.7
23 November 1980	Italy (Southern part)	3,000	7.2
28 July 1981	Kerman Province, Iran	2,500	7.3
13 December 1982	Yemen	2,800	6.0
19 September 1985	Mexico City, Mexico	9,500	8.1
10 October 1986	San Salvador, El Salvador	1,000+	7.0
06 March 1987	Ecuador	1,000+	7.0
07 December 1988	Armenia	25,000	7.8
20 June 1990	Caspian Sea, near Rasht, Iran	50,000	7.7
16 July 1990	Cabanatuan (Luzon I.) Philippines	1,621	7.8
21 October 1991	India and Nepal	2,000	7.0
12 December 1992	Flores Island, Indonesia	2,500	7.5
29 September 1993	Mumbai, India	9,748	6.3
04 October 1994	Kuril Islands of Japan and Russia	190	8.3

Date	Location	Estimated deaths	Richter magnitude
16 January 1995	Near Kobe, Japan	5,502	6.9
27 May 1995	Sakhalin Island, Russia	1,989	7.5
09 October 1995	Pacific Ocean off Colima, Mexico	57	8.0
22 November 1995	Gulf of Aquaba, between Israel and Egypt	44	7.7
17 February 1996	Irian Jaya, Indonesia	108	8.2
04 February 1997	Iran	79	6.9
27 February 1997	Pakistan (Western part)	100+	7.3
28 February 1997	Iran (North-western part)	1,000+	6.1
10 May 1997	Iran (North-western part)	1,560	7.5
22 May 1998	Bolivia (Central part)	105	6.6
30 May 1998	Afghanistan-Tajikistan Border	4,000	6.9
09 July 1998	Azores Islands	10	6.2
17 July 1998	Papua, New Guinea	2,183	7.1
29 November 1998	Indonesia	41	8.3
25 January 1999	Armenia, Colombia	1,885	6.4
17 August 1999	Turkey (North-western part)	17,118	7.4
20 September 1999	Nantou, Taiwan	2,101	7.6
12 November 1999	Turkey	843	7.5
04 May 2000	Sulawesi, Indonesia	35	7.6
04 June 2000	Southern Sumatera, Indonesia	97	7.9
06 December 2000	Turkmenistan	11	7.5
13 January 2001	El Salvador	1,100	7.9
26 January 2001	Gujarat, India	20,085	7.7
26 December 2003	Bam, Iran	40,000	6.3
26 December 2004	Sumatra-Adaman	2,50,000+	9.3
08 October 2005	Kashmir, India and Pakistan	79,000	7.6
15 November 2006	Japan (North)	—	8.1
15 August 2007	Peru	520	8.0



Volcanoes

"About 60 volcanoes erupt on land each year and at any given time there may be 20 that are currently in eruption. Some volcanoes release small amounts of gas and rock almost continually, but others undergo periods of violent release, or eruptions. Some times the volcano seems to explode, but in most cases a side of the mountain bursts from pressure within or the mountain collapses because the magma reservoir has emptied."

*Discover Science Almanac: The Definitive Science Resource,
New York, 2003*

Living in the shadow of a volcano means living in constant danger. An active volcano may erupt with little warning and a volcanic eruption may be an extremely violent event, capable of destroying entire cities. The volcanic explosion of Krakatoa, an island between Java and Sumatra in the Pacific Ocean in 1883 was said to have been the equivalent to 26 of the most powerful hydrogen bombs ever exploded. The dense cloud produced by the eruption reduced the Sun's heating effect on the Earth by 20 percent. The dust circled the globe within a month and it produced blazing red sunsets as far afield as

London. Such is the power and dramatic effect of a volcanic explosion.

However, not all volcanic explosions are violent.

What are volcanoes?

Volcanoes are locations on the Earth's crust where rising molten rock and hot gases break through the crust. A volcano may be defined as one or more openings/vents/ruptures in the Earth's surface, through which hot, molten rock (lava), rock fragments, ashes, gases etc., are ejected from the Earth's interior.



Volcanic explosion

Volcanoes are named after Vulcan, the Roman God of Fire. The Romans believed that he lived under an island called Vulcano in the Mediterranean Sea. This island is a volcano. They believed Vulcan was a blacksmith who made weapons for the other gods. It was when Vulcan made these weapons, that the Earth shook and the island erupted.



Vulcan, the Roman God of Fire

Mountains formed by rock building up around the opening of a volcano are also called volcanoes. This means the term volcano not only refers to the opening or the vent, but also the mountain formed by the accumulation of the ejected materials such as solidified lava, rock fragments, and cinders. Heights and shapes of volcanic mountains show a great variation.

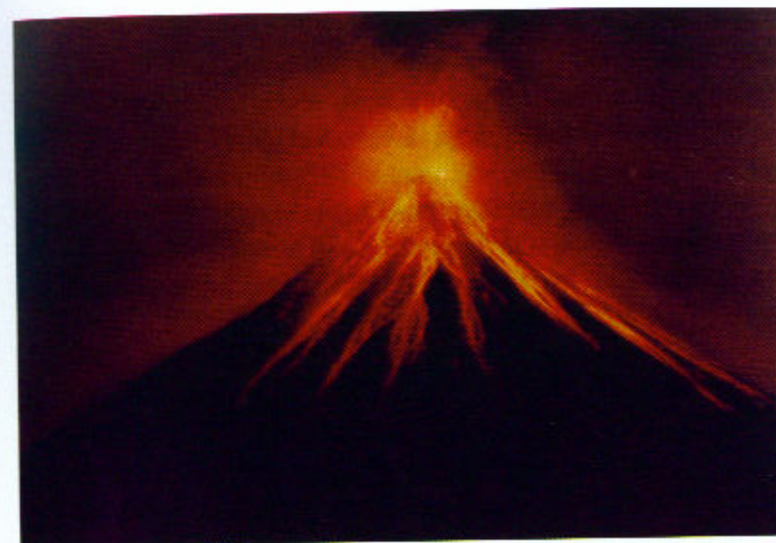
Heights of some volcanic mountains are indicated below:

Mount Popocatepetl, Mexico	5422 m
Mount Aconcagua, Argentina	6960 m
Ojos del Salado, Chile	6887 m
Mount Kilimanjaro, Tanzania	5273 m
Mount Arafat, Turkey	5165 m

Looking at a Volcano

The most popular, almost picture post card description of a volcano is that of a mountain spewing fire from its peak. What is not immediately apparent is that a volcano is an opening in the Earth's surface, through which hot, molten rock, ash and gases escape from deep below the surface. Over time, these extruded material form mountains or mountain-like features. Therefore, unlike most mountains, which are pushed up from below, volcanoes are built up by an accumulation of their own products.

A more or less cup-shaped or basin-shaped depression is found atop a volcano. This is called the crater. All volcanoes contain a central vent underlying the summit crater. The central



Mayon volcano

vent is connected deep down to a magma chamber, which is the main storage area for the eruptive material. The sides of the volcano often contain fractures that descend downward toward the central vent. Such fractures may also tap the magma source and act as conduits for eruptions along the sides of the volcano's body. Sideways directed volcanic explosions, known as "lateral blasts", can shoot large pieces of rock at very high speeds for several kilometres. These explosions can kill by impact, burial, or heat and generate cone-shaped accumulations of volcanic material, called parasitic cones. Fractures can also act as conduits for escaping volcanic gases, which are released at the surface through vent openings called fumaroles.

The size of the summit crater varies widely from volcano to volcano. Apparently there is no connection between the size of the crater and the height of the volcano. There is also no connection between the size of the crater and the explosive power of a volcano.

Very broad and comparatively shallow craters are called calderas. Caldera is a Spanish word and it means "caldron". When a former volcanic cone collapse it becomes wider and shallower and that is how a caldera is formed. Many calderas form lakes when they are filled with water. Crater Lake in the Crater National Park is a beautiful example of this kind of lake.

Types of Volcanoes

Although every volcano has a unique eruptive history, most can be grouped into three main types based largely on their eruptive patterns and their general forms.

The three types are:

- **Active:** An active volcano is one that is currently erupting or is showing signs of doing so (rumbling, trembling, discharging significant amounts of gas). It may also be a volcano that has erupted in the past and is considered



Arenal Volcano

likely to do so in the future again. A volcano is regarded active as long as the magma reservoir is present.

- **Dormant:** A dormant volcano is one that has erupted in historical times but is now quiet. It may show sign of activity in the form of hot springs or mild earthquakes. A dormant volcano still has magma but is not moving.
- **Extinct or Dead:** An extinct volcano is one that has not erupted in historical times. Extinct volcanoes are those that scientists consider unlikely to erupt again. A volcano is extinct when all its magma cools to form rock or is completely ejected. Whether a volcano is truly extinct is often difficult to determine. Some volcanoes called supervolcano calderas can have eruptive lifespans measured in millions of years. A caldera that has not produced an eruption in tens of thousands of years is likely to be considered dormant instead of extinct.

This differentiation is largely subjective in nature and sometime leads to confusion. The confusion is further compounded by the fact that the span of recorded history differs from region to region, ranging from 3000 years in the Mediterranean, to a mere 200 years in Hawaii. According to the Smithsonian Global Volcanism Programme's definition of an active volcano, a volcano is active if it has erupted during the last 10,000 years. It is not very easy to declare a volcano extinct. For example, the Yellowstone Caldera in Yellowstone National Park USA has not violently erupted for about 650000 years. There was some lava flow some 70000 years ago. But scientists do not consider it as an extinct volcano.

Today, there are many active volcanoes worldwide. There are about 550 to 580 volcanoes that can be considered "active". The number of dormant volcanoes may be twice that. Apart from these there are a large number of volcanoes in the deep ocean at mid-ocean ridges.

In India Barren-1 is a volcano on the Barren Island. There is another one in Narcondum. Both are located in the Andaman & Nicobar Islands. The volcano on Barren Island is the only active volcano in the Indian Subcontinent. On 08 June 2005 there were media reports of “mud and smoke” being ejected from the Narcondum volcano, currently classified as a dormant volcano by the Geological Survey of India.

Volcanic Eruption

Volcanic eruptions cannot be predicted. Also, most volcanoes do not erupt continuously. A volcano may remain inactive for thousands of years. However, the actual eruption is not usually without warning. Volcanic eruption is often preceded by earthquake.

Early Warning Signs

Before the eruption there are loud rumblings, caused probably by the movement of molten rock and gases. The rumblings resemble the sound of thunder. Volcanoes produce a wide-range of sounds.

Mark Twain wrote about the noises at Kilauea in “The Great Volcano of Kilauea”. He wrote: *“The noise made by bubbling lava is not great, heard as we heard from our lofty perch. It makes three distinct sounds—a rushing, a hissing, and a coughing or puffing sound; and if you stand on the brink and close your eyes it is no trick at all to imagine that you are sweeping down a river on a large low-pressure streamer, and that you hear the hissing of the steam about her boiler, the puffing from her escape pipes and the churning rush of water abaft her wheels”*.

There are other signs such as the sudden appearance of hot spring near the vicinity of the eruption site or the rise or fall in the level of water in nearby lakes.

The Eruption

During the actual eruption, an explosion takes place and which is followed by the sudden release of vast quantities of gases (including superheated water), rocks, stones, ashes, lava and other materials. The sound generated by the explosion can be heard at a great distance. The sound of the Tamboa volcano (1915) in Indonesia could be heard at a distance of 1500 kilometres. The ground adjoining the eruption site shakes violently.

Depending on the power of the explosion, the ejected material in the form of a vertical column reaches great heights. The intense friction among the particles coming out of the vent creates static electricity, which in turn generates flashes of lightning and thunder. Explosions may tear away part of the summit of the volcanic mountain as it happened when the Mount St. Helen erupted in 1980.

The Fallout

Volcanoes are a natural hazard. A volcanic eruption means unleashing of violent energy, which at times can mean disaster. For those who live or carry out activities near or around volcanoes the risk is omnipresent. Monitoring active and dormant volcanoes is essential for the safety of local people.

Understanding Volcanic Behaviour

It is the heat within Earth that is responsible for volcanic eruptions. The heat within the Earth is linked to the way the Earth was formed. At the beginning of the formation of the Earth, it was in a completely molten state. It was too hot to sustain life. Then gradually it cooled down. As it did so, the Earth's crust first took shape. But the Earth has still not cooled down completely. It is believed that some of this original heat

Type of Volcanic Activities					
Description	VEI	Plume Height	Classification	Frequency	Example
Non-explosive	0	<100m	Hawaiian	Daily	Kilauea
Gentle	1	100-1000m	Hawaiian/strombolian	Daily	Stromboli
Explosive	2	1-5 km	Strombolian/Vulcanian	Weekly	Galeras, 1992
Severe	3	3-15 km	Vulcanian	Yearly	Ruiz, 1985
Cataclysmic	4	10-25km	Vulcanian/Plinian	10s of years	Galunggung, 1982
Paroxysmal	5	>25km	Plinian	100s of years	Mt. St. Helens, 1980
Colossal	6	>25km	Plinianultra-Plinian	1000s of years	Kakaeu, 1883
Super-Colossal	7	>25 km	Ultra Plinian	1000s of years	Tambora, 1815
Mega-Colossal	8	>25km	Ultra-Plinian	10,000s of years	Yellowstone, 2.2 million years ago

has been retained by Earth. Its core is still hot and in a molten state. Heat is also generated by the disintegration of radioactive elements like uranium and thorium present in the rocks. The heat within the Earth is so much that it melts the rocks. The molten rock beneath the crust is called magma. Magma also contains steam and other gases.

The density of magma or the molten rock is less than the solid rocks surrounding it. The viscosity of magma depends on its temperature, water content and the amount of silica in it. The higher the silica content, the thicker is the magma. Dissolved gases make the magma even lighter than the solid rock. Pressed by heavier rocks the magma is pushed upwards and eventually it makes its way to the surface of the Earth either via volcanic eruption or through fissures on the surface.

Classifying Volcanic Activity

There are many different kinds of volcanic activity and eruptions:

- Phreatic eruptions (steam-generated eruptions).
- Explosive eruption of high-silica lava (e.g., rhyolite).
- Effusive eruption of low-silica lava (e.g., basalt).
- Pyroclastic flows, lahars (debris flow).
- Carbon dioxide emission.

Volcanic activities are often accompanied by earthquakes, hot springs, fumaroles, mud pots and geysers.

The Power of Volcanic Eruptions

Volcanoes have been classified based on a parameter called Volcanic Explosive Index (VEI). The VEI indicates how powerful an eruption is.

Lava

The most typical product of a volcanic eruption is lava. It is inextricably linked to the popular perception of a volcanic eruption. Interestingly, despite the mental association, in some volcanic eruptions, lava may not be ejected at all. The great eruption of Mount Pelee in 1902 did not eject any lava. In a volcanic eruption, lava generally comes out after the discharge



A typical product of a volcanic eruption is lava

of superheated steam and other gases. Immediately after coming out of the volcanic crater, the lava looks red-hot or white-hot

Normally lava flows over the edges of the crater. Lavas are also ejected out of fissures in the Earth's crust. Such eruptions, called fissure eruptions, do not pile up to form volcanic mountains. The lava coming out of the fissure eruption spreads over large areas. In Western India an area of more than 500000 square kilometres is covered with lava that has

solidified over time. The deposition has an depth of 600 metres. Similar flows in parts of USA cover an area of about 575,000 square kilometres. The lava cover has an average depth of 150 metres. Fissure eruptions are very common in Iceland, an island formed largely by volcanic activity.

When the lava is too viscous it cannot flow. The viscosity of lava increases when its temperatures become relatively low or it has very low gas content. Highly viscous lava, which does not flow, is pushed out from the volcanic vents and it piles up in the form of large domes called plug domes. In some cases towers are formed.

Initially the movement of the lava is fast but as it cools down its viscosity increases and the speed decreases. The speed of lava flows is dependent on the viscosity of the lava and the slope of the land on which it is moving. Lava has a temperature of about 1100 degrees Celsius, which is hot enough to melt steel. Lava is poor conductor of heat. Thus it takes very long time to cool. The surface of the lava may be cool enough for one to walk on it but beneath it may be red hot. Lava ejected from the eruption of Mount Etna in 1787 was seen issuing steam even after 43 years.

Types of Lava

Volcanoes are also classified by the composition of lavas erupted. Lavas are broadly classified into four different compositions.

- **Felsic Lava:** When the erupted magma contains more than 63 per cent silica, the lava is termed felsic. Felsic lavas are also called rhyolites. Felsic lavas are highly viscous and they erupt as domes or short, stubby flows. Such lavas form stratovolcanoes or lava domes. A volcano formed from felsic lava is exemplified by Lassen Volcanic National Park in California, USA. Lassen Peak is a large lava dome.

- **Intermediate Lava:** When the erupted magma contains 52 to 63 percent silica, the lava is of intermediate composition. Such volcanoes are called “andesite” volcanoes and they generally occur above subduction zones. Mount Merapi in Indonesia is an example of andesite volcano.
- **Mafic Lava:** When the erupted magma contains less than 52 percent but more than 45 per cent silica, the lava is called mafic lava. Such lava contains higher percentage of magnesium (Mg) and iron (Fe).
- **Ultramafic Lava:** When the silica content of erupted magma is 45 per cent or less, the lava is called ultramafic lava. Also known as komatiites, this form is the hottest and most fluid of lavas. Such lavas are very rare.

Rocks

Rocks, stones and cinders of different sizes are spewed out in huge quantities during volcanic eruptions. Sometimes, depending on the explosive power of the volcano, these may be hurled to great heights. For example, the 1779 eruption of Vesuvius hurled cinders to a height of 300 metres.

Ashes

A volcanic eruption is often accompanied by huge ash emission. It has been reported that the eruption of Cosiguina, (or Consequina) ejected 4 billion of cubic metres of ash. The winds carried the ash to a distance more 1300 kilometres. The emitted ash may be so thick that it can completely block sunlight and create an eerie darkness around the vicinity of the volcano. The darkness is only broken by intermittent flashes of light from the crater and the glow of the molten lava. Ash emitted by volcanic eruption, particularly the fine particles persists in the sky for a years and it circles the Earth many times. Such dusts result in gorgeously colourful sunsets and sunrises.

In 1883, the vast amount of ash thrown out during the eruption of Krakatoa, darkened the sky 240 kilometres away. When the emitted ash is mixed with the rain caused by condensation of the steam coming out of the volcano, it converts into sticky mud and the takes the shape of mud river. This creates havoc as it buries everything in its path.



Ash Eruption

The eruption of Vesuvius in 79 AD, buried the ancient city of Herculaneum under approximately 20 metres of lava, mud and ash.

Gases

The amount of volcanic gases ejected may widely vary from one volcano to another. The most abundant volcanic gas is water vapour, followed by carbon dioxide and sulphur dioxide.

Other significant volcanic gases are hydrogen sulphide, hydrogen chloride and hydrogen fluoride. Hydrogen, carbon monoxide, halocarbons, organic compounds, and volatile metal chlorides are also found in different amounts in volcanic emissions. Volcanic gases are natural contributor to acid rain. Sulphur dioxide ejected by volcano converts to sulphuric acid (H_2SO_4) in the presence of water, which in turn condenses rapidly in the atmosphere to form the sulphat albedo or sulphat aerosol. Volcanic activity releases about 130 to 230 teragrams of carbon dioxide each year.

Cinder Cones

Cinder cones are built from particles and blobs of congealed lava ejected from a single vent. As the gas-charged lava is blown violently into the air, it breaks into small fragments that solidify and fall as cinders around the vent to form a circular or oval cone. The eruptions that produce cone-shaped hill perhaps 30 to 400 m high are mostly short-lived. Most cinder cones erupt only once. The simplest volcanoes are cinder cones. Cinder cones have a bowl-shaped crater at the summit and only grow to about the size of a hill, say 100 feet. Also called Scoria cones.

Paricutin in Mexico is the most famous cinder cone volcano.

Shield Volcanoes

Shield volcanoes with shallowly-sloping sides. These are large, tall and broad, with flat, rounded shapes. It is believed that the oldest continental regions of Earth are the remains of ancient shield volcanoes. Shield volcanoes release liquid lava that flows from the crater and down the sides of the volcano. Because of the fluidity of the lava, major explosive eruptions do not occur.

The Hawaiian volcanoes are examples of shield volcanoes. Mauna Loa and Kilauea, two of the world's most active volcanoes are examples of shield volcanoes.

Composite Volcanoes

Composite volcanoes are the most majestic volcanoes. They are tall, symmetrically shaped, with steep sides, sometimes rising 10,000 feet high. Composite volcanoes are also called strato-volcanoes. They are composed of lava flow and other ejecta such as ash, cinder etc., in alternate layers.

Mount Fuji in Japan, Mount Cotopaxi in Ecuador, Mount Shasta, Mount Lassen, Mount Hood, Mount St. Helens and Mount Rainier in USA, Mount Pinatubo in the Philippines, and Mount Etna in Italy are classic examples of composite volcanoes.

Super volcanoes

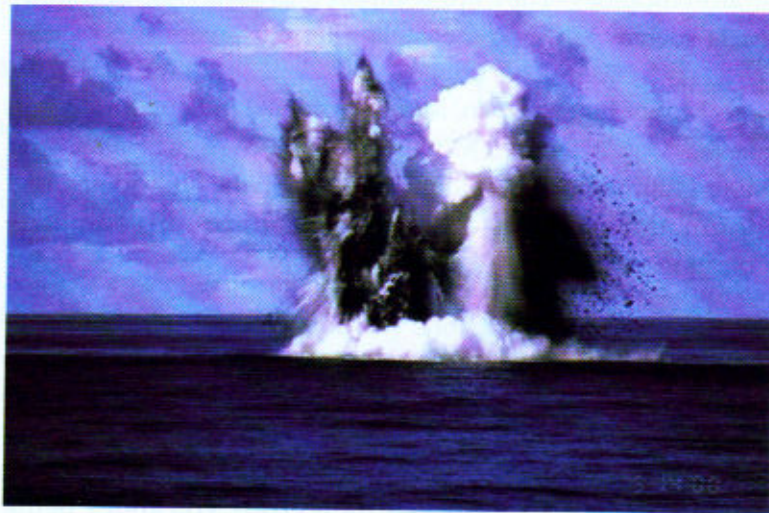


Super Volcano

Large volcanoes having large calderas are called super volcanoes. They are the most dangerous volcanoes being capable of causing devastation on an enormous scale, sometimes affecting a whole continent. Eruptions on such a large scale can cause severe cooling of global temperature. Yellowstone Caldera in Yellowstone National Park, Lake Topo in New Zealand and Lake Toba in Sumatra are examples of super volcanoes.

Submarine Volcanoes

There is lot of volcanic activity going on under the oceans. Volcanoes operating under the ocean are called submarine volcanoes. Undersea volcanic activity begins when cracks form under the sea because of plate movement. The cracks are more easily formed in the ocean than on land, because the Earth's crust under the ocean is only 5-8 km thick compared to 32-40 km on land.



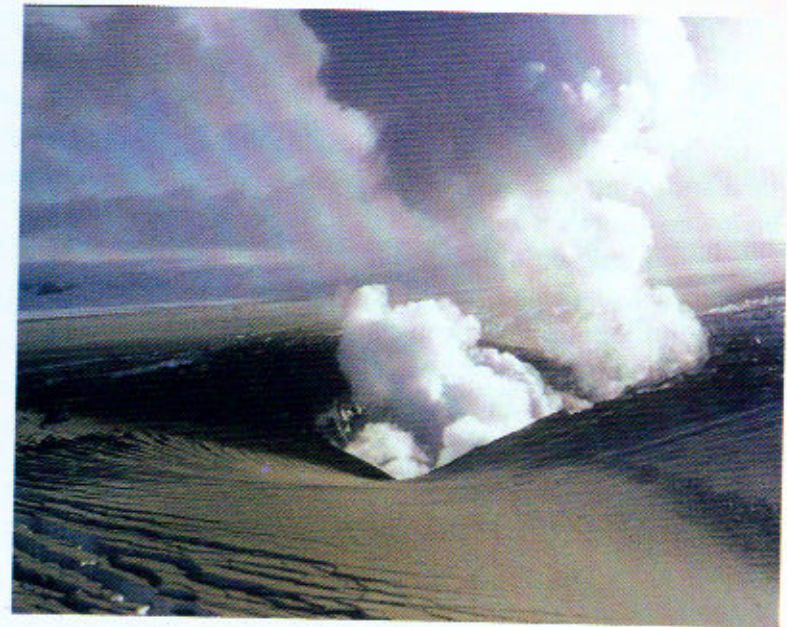
Submarine Volcanoe

Many volcanoes that began under the sea have now become full-fledged islands like Hawaii and Iceland. These volcanic islands were formed by gradual accumulation lava, layer after layer, over a long period of time. This is a gradual process. But sometimes there is sudden formation of an island because of the eruption of a submarine volcano. But an island formed this way cannot withstand onslaught of the sea and usually vanishes after a few months (although a few may be of a somewhat permanent nature). One can see such sudden

appearances and disappearances of volcanic islands in the Mediterranean Sea.

Subglacial Volcanoes

Volcanoes developed underneath icecaps are called subglacial volcanoes. During the eruption, the heat of the lava from the subglacial volcano melts the overlying ice. Melting of the icecap



Subglacier volcano

leads to the collapse of the lavas on the top leaving a flat-topped mountain. The water quickly cools the lava, resulting in pillow lava. Pillow lavas are bulbous, spherical, or tubular lobes of lava. Sometimes the pillow lavas break off and roll down the volcano slopes. The flat-topped, steep-sided subglacial volcanoes are called tuyas. The name *tuya* comes from the Tuya region of British Columbia where many subglacial volcanic

features have been described. In Iceland, such volcanoes are also known as table mountains.

Why are Volcanoes Formed?

Before the scientific explanation emerged, people tried to explain volcanic activity in many ways. According to ancient accounts, the true cause underlying volcanic activity was divine intervention.

Later, it was thought that chemical reaction were responsible for volcanic behaviour. It was also thought that a thin layer of molten rock existed near the surface. Athanasius Kirschir (1602-1680), who had witnessed the eruption of Mount Etna and Mount Stromboli and was adventurous enough to be lowered into the crater of Vesuvius, then on the brink of eruption, proposed a theory. He proposed that the cause of volcano activity be attributed to an Earth with a central fire and to numerous other causes resulting from burning of sulphur, bitumen and coal.

Current Explanations of Volcano Formation

Today, we know that volcanic activities generally arise where two to three tectonic plates interact with each other. Unlike earthquakes, volcanoes are usually not created where two tectonic plates slide past one another.

Non-hotspot Inter-plate Volcanoes

Volcanoes can also form where the Earth's crust "stretches" and become thinner. Volcanic activity caused because of this, is called "non-hotspot inter-plate volcanism". Such volcanic activity is seen in the African Rift Valley, the European Rhine Graben (A graben is a depressed block of land bordered by parallel faults. The word Graben is German for ditch.) with its Eifel volcanoes, and the Rio Grande Rift in North America.

Divergent plate boundaries

Sometimes tectonic plates move away from one another. Such plates are called divergent plates. Divergent plate boundaries create new seafloor and volcanic islands. New oceanic crust is continually formed by hot molten rock slowly cooling down and solidifying. In these places, the crust is very thin. In such a situation the volcanic activity is caused by the force created by the diverging plates. The main part of the mid-oceanic ridges are at the bottom of the ocean, and most volcanic activity is submarine. Volcanoes such as the Hekla (Iceland) are formed when the mid-oceanic ridge comes above sea-level. The Mid-Atlantic Ridge, has volcanoes which are caused by "divergent tectonic plates".

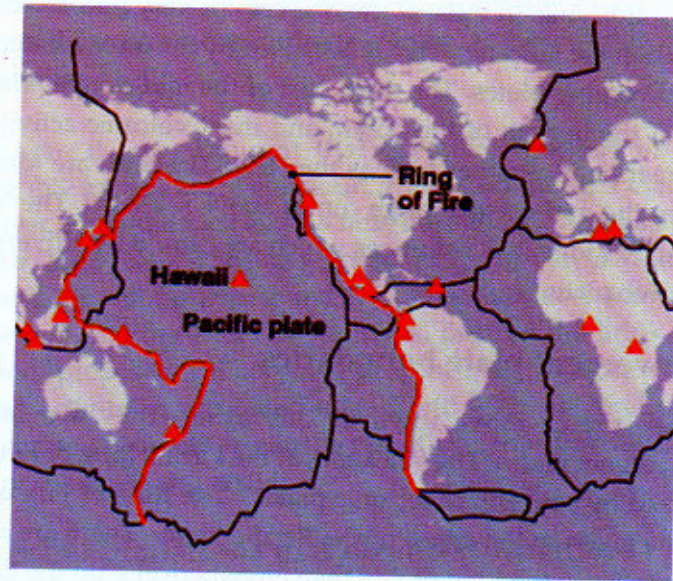
Convergent plate boundaries

When plates move towards one other, they are called convergent plates. The volcanoes at the Pacific Ring of Fire are caused by convergent tectonic plates. The Ring of Fire is the name given to the edges of the Pacific Plate. There are more volcanoes in the Ring of Fire than anywhere else on the Earth. Along the edges, plates grind past each other and one plate dives below the other. This is called subduction and it forces magma to go up. The result is volcanic activity. In places where one tectonic plate submerges beneath another at a deep ocean trench, the crust melts and becomes magma. This magma causes the formation of the volcano. Typical examples are the volcanoes in the Pacific Ring of Fire, and also Mount Etna and Mount Vesuvius.

Hotspots

Hotspots are located on top of mantle plumes, where the convection of Earth's mantle creates a column of hot material

that rises until it reaches the crust, which tends to be thinner than in other areas of the Earth. The term "plume" was originally used to indicate a rising column as one sees the column of steam and ash above some volcanoes. The tremendous temperature of the plume causes the crust to melt



Hot spot in pacific Ocean

and form pipes, through which magma is vented. It appears that rising magma form bubbles and this causes a discontinuity between the arrivals of different batches of rising molten rock. Mantle plume remains in the same place but the motion of the tectonic plate above the plume makes the hot spot seem to move.

There are many locations on the Earth's crust where hot spots are found. The most famous hotspot is in the Pacific Ocean and it continues to form new volcanic islands. The Hawaiian Island, was formed by volcanic activity on this

hotspot. It is believed that the islands the Azores and the Galapagos were formed because of this kind of activity. There is a plume deep below the Yellowstone National Park in the United States which had produced a great eruption in the past. Today its effect is confined to geysers and hot springs.

Petitspots

In July 2006, unusual volcanic activity that could not be slotted into any of the above-mentioned categories spurred scientists to create a new category called Petitspots.

The location of this volcanic activity was far from any plate boundary and it was too small to be changed by a mantle plume. To explain this unusual volcanic activity a new theory was proposed. According to this new theory submergence of tectonic plates causes stresses all over the plate and this results in cracking of the plate. This creates conduits for the magma to move up and erupt. Such locations are called petitspots.

What makes the discovery so potentially revolutionary is that these small volcanoes appear to require no extraordinary heat from below to melt the rocks under the crust. Instead, the lava comes from areas between the crust and the underlying mantle – the malleable zone called the asthenosphere – where partially melted rocks can exist without any help from "mantle plumes".

Some scientists who do not believe in the plume theory are taking this discovery as a "proof" of their ideas.

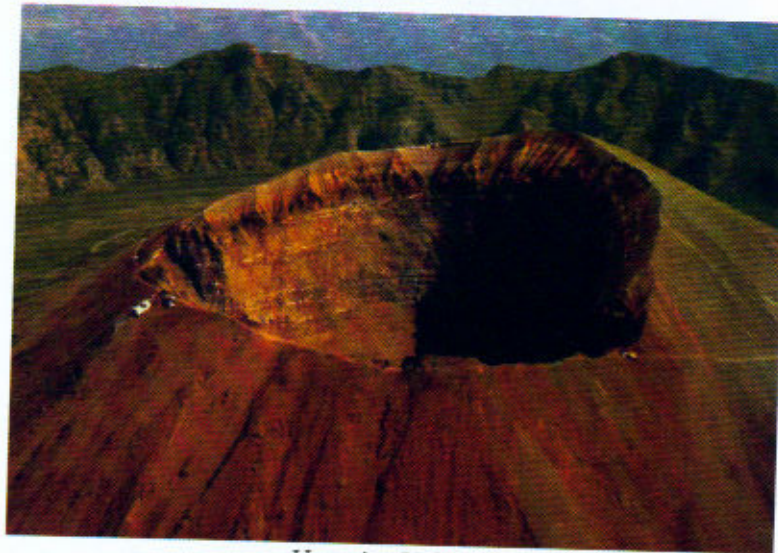
Deadly Volcanic Eruptions

Every year about 60 volcanoes erupt in different parts of the world. However, most of these volcanic activities are fairly weak.

Vesuvius

The oldest recorded eyewitness account of a volcanic eruption was written by Pliny the Younger (c.62-c.113 AD), the Roman writer and orator and the nephew of Pliny the Elder. He described the eruption of Mount Vesuvius that took place on 24 August 79 AD.

The City of Pompeii, was buried under tons of stone and ash as Mount Vesuvius erupted. The eruption claimed more than 3000 lives. Pliny the Elder, was one of those killed. Pliny



Vesuvius Volcano

the Younger, witnessed the disaster from the nearby town of Misenum before fleeing to a safer place. He described the incident in detail in two letters he sent to his friend Tacitus (c.55-120 AD), a Roman historian.

He wrote: "My uncle was at time with the fleet under his command at Misenum. About one in the afternoon, my mother

desired him to observe a cloud of very unusual size and appearance. I cannot give a more exact description of its figure than by comparing it to a pine tree, for it shot up at a great height in the form of a trunk, which extended itself at the top into several branches... My uncle ordered large galleys to be launched and he went aboard one with the intention of assisting many others, where villas stand extremely thick upon the coast. Cinders, which grew thicker and hotter, fell into the ships, followed by pumice stones blackened, scorched, and cracked by fire. The sea ebbed suddenly from under, then, while the shore was blocked up with landslides from the mountains. We beheld the sea sucked back, and as if it were repulsed by the convulsive motion of the Earth; it is certain at least the shore was considerably enlarged, and now held many sea animals captive on the dry sand. On the other side, a black and dreadful cloud bursting out in gusts of igneous serpentine vapour now and again yawned open to reveal long fantastic flames, resembling flashes of lightning but much larger... You could hear the shrieks of women and crying children and the shouts of men. Many were lifting their hands to the gods, but the greater part were imagining that there were no gods left anywhere, and the last and eternal night had come upon the world".

Krakatau

One of the greatest of all volcanic disasters occurred in recorded history when Krakatau, a small island of Indonesia exploded in 1883. The site of the explosion was at a place where Indo-Australia plate subducts the Pacific plate. The sound was heard across the Indian Ocean, as far away as Rodriguez Island, 4,653 kilometres to the west, and Australia, 3,450 kilometres to the east. The explosion was believed to be equal to 200 million tonnes of TNT. A thick black pillar of smoke and ash three times as high as Mt. Everest rose into the atmosphere. The



Krakatau

explosion triggered a series of tsunamis which produced tremendously destructive waves, 30 metres tall. The huge waves created when Krakatau erupted were responsible for most of the 36,000 deaths associated with the eruption.

The legacy of Krakatau lives on. Phoenix-like, Anak Krakatau (Child of Krakatau) has risen from the crater left when Krakatau, disappeared. The volcano's circular crater sits southwest of the centre of the island and is surrounded by fresh lava flows and ash. The black shores of the island are scalloped where the flows have solidified in the ocean.

Keeping Track of Volcanoes

Being forewarned is being forearmed. Since many volcanoes give us warning signals before they erupt, scientists monitor volcanoes closely, always alert to detect the first sign of activity.

List of Large Volcanic Eruptions

	Year of eruption	Name of the volcano	Number of deaths	Major Cases of death
1.	79 AD	Vesuvius, Italy	3,360	Ash flows and falls
2.	1631 AD	Vesuvius, Italy	3,500	Mud flows, lava flow
3.	1640 AD	Komagatake, Japan	700	Tsunami
4.	1741 AD	Oshima, Japan	1,475	Tsunami
5.	1772 AD	Papandayan, Indonesia	2,957	Ash Flows
6.	1783 AD	Laki Iceland	9,350	Starvation
7.	1783 AD	Asama, Japan	1,377	Ash flows, mud flows,
8.	1792 AD	Unzen, Japan	14,300	Volcano collapse, tsunami
9.	1814 AD	Mayon, Philippines	1,200	Mud flows
10.	1815 AD	Tambora, Indonesia	92,000	Starvation
11.	1822 AD	Galunggung, Indonesia	4,011	Mud flows
12.	1845 AD	Ruiz, Colombia	700	Mud flows
13.	1877 AD	Cotopaxi, Ecuador	1,000	Mud flows
14.	1883 AD	Krakatau, Indonesia	36,417	Tsunami
15.	1902 AD	Mt. Pelee, Martinique	2,902	Ash flows
16.	1902 AD	Soufriere, St. Vincent	1,680	Ash flows
17.	1911 AD	Taad, Phillipines	1,335	Ash flows
18.	1919 AD	Kelut, Indonesia	5,110	Mud flows
19.	1951 AD	Hemington, Papua N.G.	2,942	Ash flows
20.	1953 AD	Hibok-Hibok, Phillcippines	500	Ash flows
21.	1963 AD	Agung, Indonesia	1,184	Ash flows
22.	1982 AD	El Chicon, Mexico	2,000	Ash flows
23.	1985 AD	Ruiz, Colombia	23,000+	Mud flows
24.	1991 AD	Pinatubo, Philippines	800	Roof collapse and diseases

Volcano monitoring basically means keeping a detailed “diary” of the changes—visible and invisible—in a volcano and its surroundings.

The clues scientists look out for include marked increase or decrease of steaming from known vents; emergence of new areas from which steam has begun to issue; development of new ground cracks or widening of old ones; unusual or inexplicable withering of plant life; changes in the colour of mineral deposits encrusting fumaroles; and any other directly observable, and often measurable, feature that might reflect a change in the state of the volcano.

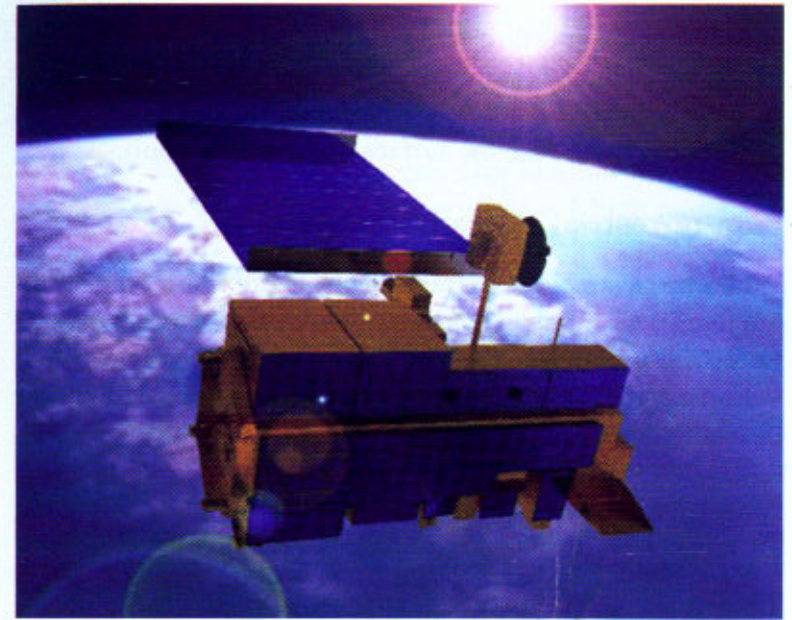
Scientists also document the course of the eruption in detail. They often make temperature measurements of lava and gas; collect the eruptive products and gases for subsequent laboratory analysis; measure the heights of lava fountains or ash plumes; estimate the flow rate of ash ejection or lava flows; and carry out other necessary observations and measurements to fully document and characterize the eruption. Such documentation, and analysis help in constructing a model of the characteristic behaviour of a given volcano or type of eruption. Daring scientists have sometimes lost their lives in the process.

Volcano monitoring also involves the recording and analysis of volcanic phenomena not visible to the human eye, but measurable by precise and sophisticated instruments. These phenomena include ground movements, earthquakes (particularly those too small to be felt by people), variations in gas compositions, and deviations in local electrical and magnetic fields that respond to pressure and stresses caused by the magma movements.

Satellite-mounted instruments such as radiometers, spectrometers and interferometers keep an eye on Earth from

space and provide continual coverage of the approximately 500 active volcanoes around the world. The information they provide enables long-term monitoring, and creation of detailed images and videos. Data collected over time can be turned into computer animation that provides dynamic evidence of change.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer was an imaging instrument flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System. It was used to obtain detailed maps



TERRA Satellite helped scientists monitor volcanoes worldwide

of land surface temperature, radiation emissions, reflectance and elevation. It helped scientists monitor volcanoes worldwide. Also flying on Terra was the Multi-angle Imaging Spectro Radiometer. Viewing the sunlit Earth simultaneously at nine widely spaced angles, this instrument produced detailed images of Earth in four colours at every angle. The multi-angle

imaging techniques allowed the detection of even tiny amounts of airborne particles, including volcanic plumes, from space.

The Shuttle Radar Topography Mission, launched on Space Shuttle *Endeavour* in February 2000, used a technique called radar interferometry. Differences between two radar images taken from slightly different locations allowed for the calculation of surface elevation. The three-dimensional shapes of volcanoes (generated with this data) yielded information on the types of eruptions, ash flow and erosion patterns.

Synthetic aperture radar interferometry data from the European Remote Sensing satellite enables researchers to see how the volcano “breathes,” or the changes within and beneath the volcano that cause the surface to expand or contract.

Non-terrestrial Volcanic Activity

While the search for extra-terrestrial life has not yielded anything so far, this is not the case with the search for extra-terrestrial volcanoes. The Earth is not the only place where volcanic activity can be seen. Volcanoes can happen on other heavenly bodies as well.

Moon

It is generally believed that our Moon has no large volcanoes. There is no direct evidence to suggest volcanic activity on the Moon. However, evidence suggests that the Moon may still possess a partially molten core. Maria (the darker patches seen on the moon), rilles and domes may be considered as volcanic features. Rilles are the long, narrow depressions on the lunar surface that resemble channels. A lunar dome is a type of shield volcano. They are typically formed by highly viscous, possibly silica-rich lava, erupting from localized vents followed by relatively slow cooling. Lunar domes are wide, rounded,

circular features with a gentle slope rising in elevation a few hundred metres to the mid-point.

Venus

It is believed that volcanic activity played a major role in shaping the surface of the planet Venus. This belief is derived from the fact that 90 per cent of Venus’ surface is basalt.

NASA’s Magellan spacecraft (1990 to 1994) used a sophisticated imaging radar to make the most highly detailed maps of Venus ever captured. Analyses of the pictures reveal that the surface of Venus is mostly covered by volcanic materials. Vast lava plains, fields of small lava domes, and large shield volcanoes are common. The presence of lava channels over 6,000 kilometres long suggests river-like flows of extremely low-viscosity lava that probably erupted at a high rate. Large pancake-shaped volcanic domes suggest the presence of a type of lava produced by extensive evolution of crustal rocks. It is believed that Venus was “resurfaced” about 500 million years ago by widespread volcanic eruptions.

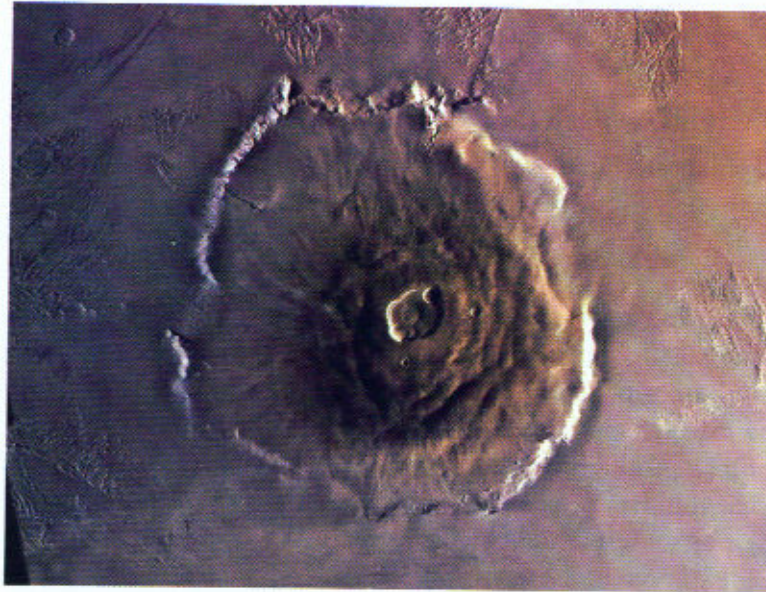
The typical signs of terrestrial plate tectonics are not evident on Venus. The planet’s tectonics is dominated by a system of global rift zones and numerous broad, low dome-like structures called coronae that were produced by the upwelling and subsidence of magma from the mantle.

Study of the Magellan high-resolution global images taken from is still providing evidence to understand the role of volcanism, and tectonism on Venus.

Mars

There are several extinct volcanoes on Mars, which have not shown any volcanic activity for many millions of years. *Arsia*

Mons, Ascraeus Mons, Hecates Tholus, Olympus Mons and Pavonis Mons are examples of shield volcanoes. These are bigger than any volcano found on Earth. *The European Mars Express* spacecraft has found evidence to indicate volcanic activity on Mars in the recent past.



Mars Volcano

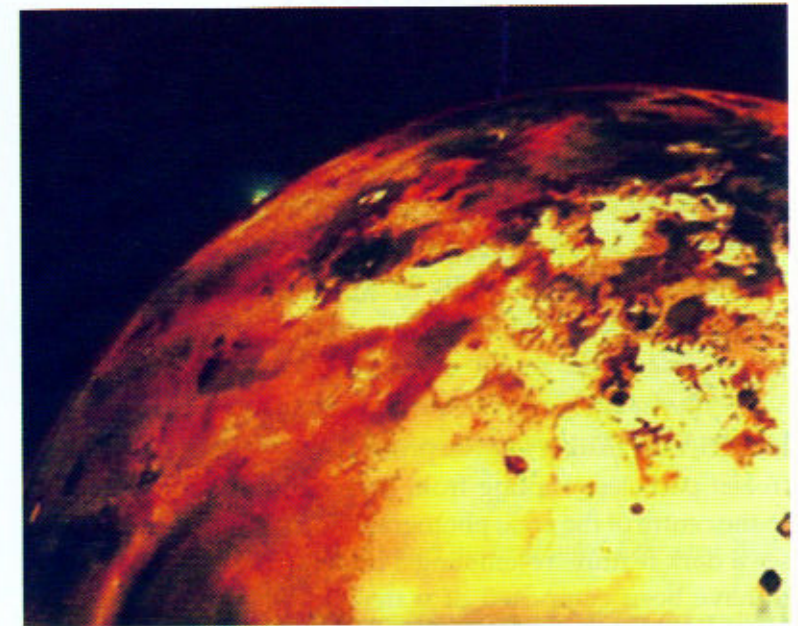
In a May 2007 Press Release NASA announced that Mars Exploration Rover Spirit had discovered evidence of an ancient volcanic explosion at "Home Plate," a plateau of layered bedrock on Mars. This was the first explosive volcanic deposit identified with a high degree of confidence by the Mars Rovers.

Jupiter

Io, a moon of the planet Jupiter, is the most volcanically active body in our solar system. There are so many volcanoes on Io that its whole surface is awash with lava. Io's volcanoes spew

sulfur, sulfur dioxide and silicate rock. Lavas erupted from Io's volcanoes are the hottest known anywhere in the solar system, with temperatures exceeding 1,500 °C.

Scientists have been studying Io's volcanic activities closely. A volcanic crater on Io was photographed by NASA's Galileo spacecraft in 1999. This volcano, named Prometheus, was found to have characteristics remarkably similar to those of the Kilauea volcano in Hawaii.



Volcanic activities at Io, a Moon of Jupiter

In February 2001, the largest recorded volcanic eruptions in the solar system occurred on Io. But this was not the first time scientists had got a "ring-side" view. In 1979, one of NASA's Voyager spacecraft had made a spectacular and unexpected discovery. Some of Io's many volcanoes were erupting! In all, *Voyager 1* observed nine volcanic eruptions. When *Voyager 2* flew past four months later it was able to

confirm that at least six of them were still erupting. This *Voyager* image of Ra Patera, a large shield volcano, shows colourful flows up to about 320 km long emanating from the dark central volcanic vent.

Europa, another moon of Jupiter, also appears to have an active volcanic system. Its volcanic activity is confined only to release of water, which freezes into ice on the cold surface. This process is known as cryo-volcanism.

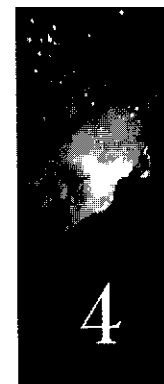
Neptune

In 1989, the *Voyager 2* spacecraft observed ice-volcanoes or cryo-volcanoes on Triton, a moon of Neptune. Cryo-volcanoes form on icy moons, and possibly on other low-temperature astronomical objects. These volcanoes erupt water, ammonia or methane. Collectively referred to as cryo-magma or ice-volcanic melt, these ejecta are usually liquids and form plumes, but can also be in vapour form.

Saturn

In 2005, the *Cassini-Huygens* probe photographed fountains of frozen particles erupting from Enceladus, a moon of Saturn. In the centre of the area, photographed, scientists could clearly see a dark feature resembling a caldera. The ejecta is thought to have been composed of water, liquid nitrogen, dust, or methane compounds.

If the science of “volcanology” truly began with the accurate descriptions of the eruption of Vesuvius in A.D. 79 that Pliny the Younger, wrote to Tacitus, today it has already transcended the boundaries of Earth, thanks to Man’s explorations in Space.



Tsunamis

“The tsunami that struck several south Asian countries on 26 December 2004 reminds us, notwithstanding our egos, that we, *Homo sapiens*, are minuscule in the face of Nature. Indeed, what would seem a small perturbation to the Earth—a very small shift of about 10 m over a small area of the ocean bed—was devastating to millions of people. Starting as a long, small-amplitude wave, barely noticeable in the open ocean, the tsunami developed into 30 feet high walls of waters as it roared down a coast and swept away everything in the way”.

Jawant H. Arakari in Resonance, February 2005.

So powerfully destructive can wave trains or a series of waves become, that this phenomenon called “Tsunami,” triggers panic in the minds of those dwelling by the sea. All oceanic regions in the world are potentially vulnerable to tsunamis. However, tsunamis are more frequent in the Pacific Ocean. Over 790 tsunamis have been recorded in the Pacific Ocean.

What are tsunamis?

The term "tsunami" is made up of two Japanese words, "Tsu" and "nami." "Tsu" means "harbour" and "nami" means "wave". So the word s mean "Harbour wave." The term was coined by Japanese fishermen, who sometimes found the area surrounding their harbour devastated though there were no discernible waves in the open water. So they called it "harbour wave."



Tsunamis behave as shallow-water waves because of their wavelengths

However, not all tsunamis occur in harbours, and in that sense, the term "tsunami" is misleading. Tsunamis have also been termed as "tidal waves." But again, tsunamis are unrelated

to the tides and describing a tsunami as a tidal wave is misleading as well. Scientists sometimes describe tsunamis as "seismic sea waves". But the term "seismic sea wave" is also misleading because a non-seismic event such as a landslide or meteorite impact may also generate tsunamis.

In scientific terms, a tsunami consists of a series of waves that travels across the ocean with exceptionally long wavelengths. The speed of the waves decreases as they approach the shore and their heights increase. In case the first part of a tsunami that reaches the coast is a trough, rather than a crest of the wave, the water along the shore line may recede dramatically. This exposes area that normally remains under water. In the case of a shallow slope, the recession may exceed, hundreds of metres.

Tsunami waves are of extremely long wavelength (distance between crest to crest) and long period (time between two successive waves). Tsunamis can have a wavelength in excess of 500 km and a period in ten minutes to two hours. Compared to tsunamis, wind generated waves usually have period of five to twenty seconds and wavelength of about 100 to 200 metres. Tsunamis behave as shallow-water waves because of their wavelengths. A wave is characterised as shallow-water wave when the ratio between the water depth and its wave length gets very small.

The speed of the tsunami is equal to the square root of the product of the acceleration of gravity (9.8 m/s^2) and the water depth. When the water is very deep, a tsunami can travel at high speed. Let us see what this means. In the Pacific Ocean, the average water depth is about 4000 m and a tsunami would travel at about 200 metres per second or over 700 kilometres per hour.

In deep ocean, the wavelength of a tsunami may be in excess of hundred kilometres but its amplitude (height from crest to trough) remains in the order of less than a metre. So they are not seen from air. They are also not felt by those aboard a ship in deep ocean.

A tsunami grows in height as it approaches the shore. Tsunamis arrive at a coastline as a series of successive crests and troughs - usually occurring 10 to 45 minutes apart. As they enter the shallow waters, their speed decreases to about 50-60 km/h. For example, in 15 m of water the speed of a tsunami will be only 45 km/h. However 100 or more kilometres away, another tsunami wave travels in deep water towards the same shore at a much greater speed, and still behind it there is another wave, travelling at even greater speed. As the tsunami waves become compressed near the coast, the wavelength is shortened and the wave energy is directed upward - thus increasing their heights considerably. Just as with ordinary surf, the energy of the tsunami waves must be contained in a smaller volume of water, so the waves grow in height. Even though the wavelength shortens near the coast, a tsunami will typically have a wavelength in excess of ten kilometres when it comes ashore.

The maximum height a tsunami reaches on shore is called the runup. It is the vertical distance between the maximum height reached by the water on shore and the mean sea level surface. Any tsunami runup over a metre is dangerous. The flooding by individual waves will typically last from ten minutes to a half-hour, so the danger period can last for hours. Tsunami runup at the point of impact will depend on how the energy is focused, the travel path of the tsunami waves, the coastal configuration, and the offshore topography. Small islands with steep slopes usually experience little runup - wave heights there are only slightly

greater than on the open ocean. This is the reason that islands with steep-sided fringing or barrier reefs are only at moderate risk from tsunamis.

Just like other waves, tsunamis start to lose energy as they approach the shore. Part of the energy is reflected offshore. The shoreward propagating wave energy is dissipated through bottom friction and turbulence. But such loss of energy does not render the tsunami harmless.

Tsunami waves may smash into the shore like a wall of water or move in as a fast moving flood or tide - carrying everything on their path. Either way, the waves become a significant threat to life and property. If the tsunami waves arrive at high tide, or if there are concurrent storm waves in the area, the effects will be cumulative and the inundation and destruction even greater. Tsunamis usually reach the shore with tremendous amounts of energy. The waves reaching to the coast are capable of stripping beaches of sands that may have taken many years to accumulate. They can destroy trees and coastal vegetation. The waves are capable of inundating or flooding adjoining areas. They can crush homes and other structures that are hundreds of metres inland.

What Causes a Tsunami?

Tsunamis are not tides produced by gravitational pull of the Moon or by winds. They are formed due to sudden deformation of the sea floor and resultant displacement of the overlying water. Such deformation of the sea floor is caused by an earthquake. An earthquake disturbs the water column either by uplift or subsidence of the sea floor. A tsunami can be generated when large areas of the sea floor elevate or subside. Large deformation of the Earth's crust can occur at plate boundaries. Around the margins of the Pacific Ocean, for

example, denser oceanic plates slip under continental plates in a process called subduction. Subduction earthquakes are quite notorious for generating tsunamis.

Tsunamis are formed as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium. The size of the resultant tsunami waves is determined by the quantum of the deformation of the sea floor. More the vertical displacement, the more will be the height of the waves.



Violent submarine volcanic eruption may uplift the water column and generate a tsunami

An earthquake is not the only factor for generating tsunami. Any disturbance that displaces a large water mass from its equilibrium position can cause tsunami. Underwater

(submarine) landslides triggered by earthquake or by the collapse of volcanic structures, may disturb the overlying water column and cause tsunami. The force of a violent submarine volcanic eruption may uplift the water column and generate a tsunami.

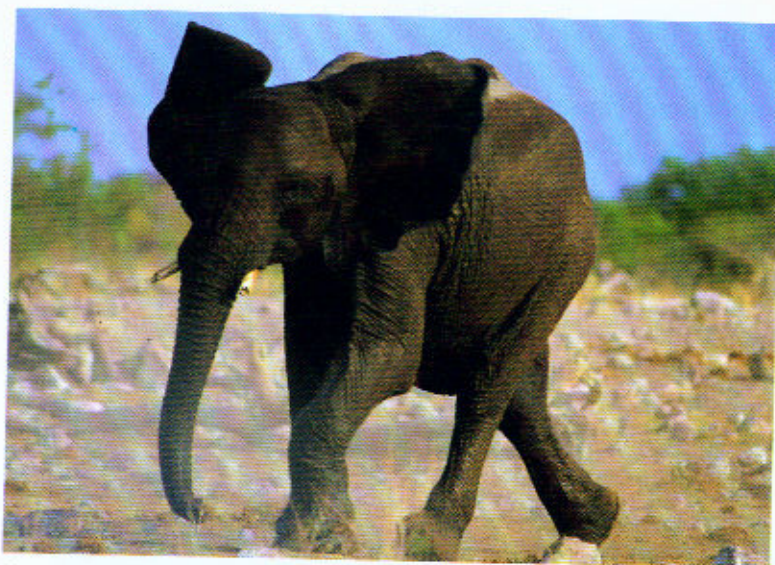
Tsunamis that are not caused by sudden deformation of plate boundaries generally dissipate quickly. They rarely reach coastline distant from the source. However, they can produce much larger local shock waves. An earthquake caused a landslide in Crillon Inlet at the head of the Lituya Bay (Alaska, USA) on 10 July 1958, generating a monstrously huge tsunami, which consumed the entire bay. By the time the wave reached the open sea, however, it dissipated quickly.

Predicting tsunami

Nobody really knows when a tsunami will strike. The occurrence of tsunami cannot be precisely predicted. It cannot even be prevented. However, there are some warning signs of an impending tsunami. But even then predicting a tsunami is not an easy task. It is still an inexact science.

Animals appear to be able to sense an approaching tsunami and move to higher ground before the waves strike the coast. This sort of behaviour was first documented in Europe, before the tsunami generated by the Lisbon earthquake struck. A similar phenomenon was noticed in Sri Lanka when the Indian Ocean tsunami occurred in 2004. It has been speculated that animals may have the ability to sense subsonic Rayleigh waves from an earthquake even before a tsunami strikes the coast.

But since not all earthquakes produce tsunamis, warnings simply based on the occurrence of earthquakes may not always be correct. According to a report, three out four tsunami



Some animals are able to sense an approaching tsunami like elephants

warnings issued since 1948 have turned out to be incorrect. The cost of false alarms can be high because it means wastage of resources and time. Computer models that make a rough prediction of tsunami's arrival and its probable impact based on information about the earthquake and the shape of the seafloor (bathymetry) and coastal land (topography) are helping in refining predictions and making them more accurate.

Any information regarding an impending tsunami should be passed to people living in areas to be affected. The information should, ideally therefore, reach the people who are trained to swing into action. However, the local people should also be educated about where to turn for information and also about how they must react to the information. If people do not know what havoc a tsunami can wreck and how they can escape from the imminent danger, mere receiving of the information is not of much use.

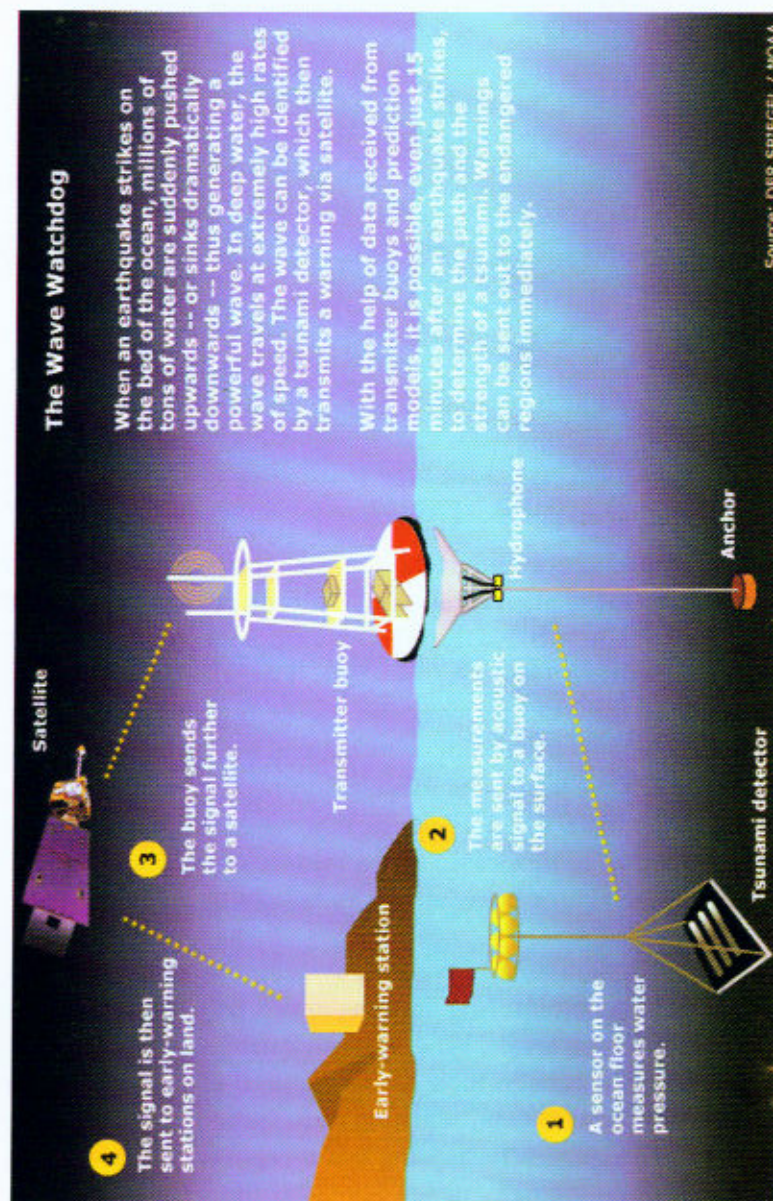
Tsunami :Points to Remember

- All low-lying coastal areas stand the risk of being struck by a tsunami.
- A tsunami consists of a series of waves. The first wave may not be the longest, the highest.
- Tsunamis move much faster than a person can run.
- A tsunami may cause the water near the shore to recede, exposing the ocean floor.
- Tsunami can travel up rivers and streams that lead to the ocean.
- There is no particular time for a tsunami to occur—it can occur at any time, day or night.
- Unlike rolling waves, tsunami waves are not “surfable”.

Tsunami Warning System

After the disastrous tsunami hit Alaska, causing devastating damage, an international Tsunami Warning System (TWS) was set up by the US National Oceanic and Atmospheric Administration (NOAA) in 1965. The US Government established the TWS to cover the Pacific region and brought into partnership the Pacific-rim nations in North and South America, China, Japan, Thailand including French islands and Russia. The TWS has a Tsunami Warning centre in Hawaii, which happen to be located in the middle of the Pacific and a place at high risk of being struck by tsunami.

The Pacific Tsunami Warning system comprises of a chain of 150 seismic monitoring stations and a network of gauges that measure sea levels. Whenever an earthquake is detected, its location and magnitude are computed. If the magnitude exceeds a certain level, warnings are issued to vulnerable regions. The gauges measuring sea levels are monitored for any abnormal changes in sea levels. If the gauges detect a budding tsunami, computer-based mathematical models are



used to calculate its speed and direction. The calculation takes into account many factors, including peculiarities in the shape of the seabed. Based on the results of the calculation, coastal areas falling in the projected path of the tsunami are warned about the developments. The tsunami warning system is triggered by seismic readings indicating a large earthquake and which in turn alerts the system and operators to look for probable tsunami indicators, especially rise in sea-levels. It takes about an hour to assimilate and analyse all the information and to issue tsunami warnings.

The tsunami warning system has been further improved by the recent development of Deep Ocean Assessment and Reporting on Tsunami (DART) system, first deployed in August 2000. A DART system consists of a seafloor bottom pressure recording (BPR) device and a moored surface buoy floating the ocean waves for real time communication. An acoustic link transmits data on the propagation of tsunami in deep water from the BPR to the buoy. Data from the buoy are transmitted to Geostationary Operational Environmental Satellite (GOES) Data Collection System. From here the data reaches the ground station where the signals are immediately disseminated to NOAA's Tsunami Working Centres.

Since tsunamis are rare in the Indian Ocean and Bay of Bengal there were no warning systems in place when disaster struck on 26 December 2004. The harsh wake-up call galvanised the country into action with plans for the Deep Ocean Assessment and Reporting System (DOASRS) being announced almost immediately.

Minimising Damage

The importance of awareness cannot be over-estimated. Education campaigns are an essential component of any working system.

Tilly Smith—an informed ten year who remembered what she had been taught in school, and was composed enough to act on that information, saved more than 100 people on 26 December 2004. Tilly and her family were vacationing in Phuket, Thailand, when the tsunami struck. She saw the sea water receding from the shore and remembered that was one of the signs of an impending tsunami. Because of the warning she issued, the beach was cleared minutes before the wave arrived. It was lucky for those present on the beach that Tilly issued the warning in time. Usually those vacationing on sea beaches are unaware of what the receding waters portend. They give in to the temptation of exploring the exposed surface of the sea bed and so venture far out and are swept away as the waves come rushing in. On Phuket, that day, the human death toll was considerably less thanks to little Tilly Smith who had the knowledge and also the presence of mind to put it to use.

Before a Tsunami

- People living in coastal areas and tourists should be familiar with the tsunami warning signs. For example,
 - A strong earthquake lasting 20 seconds or more in near vicinity of the coast may trigger a tsunami.
 - A noticeable rapid rise or fall in coastal water may be an indication of an approaching tsunami.
- A proper mechanism should be in place to pass on relevant information through local public warning systems
- Tsunami evacuation routes should be built in advance and widely publicised. People should be intimately familiar with escape routes so that they are able to follow these routes even at night or during unfavourable weather. Regular practice sessions should be organised during normal times to build up a familiar pattern of use.

- Signboards directing people to safe grounds should be placed in prominent places.
- Land use in tsunami hazard areas should be reviewed on regular basis. Critical facilities such as hospitals, police station, petroleum storage tanks, power stations, schools and other high occupancy buildings, should be built in safe areas. It is possible to minimise damage caused by tsunami by land-use planning and efficient evacuation strategies.
- Visitors should gather tsunami warning and evacuation information beforehand.
- Local newspapers, TV channels, radio stations should publicise information regularly.

During a tsunami

- There is only one way to escape the wrath of tsunami and that is to go as far away from it as possible. No one can fight it. It is best to evacuate the area as soon as the first word about an impending tsunami reaches. Delays in action may compromise safety if escape routes are cut off. Following the disaster, it is likely that roads may become impassable or blocked.
- Stay away from the beach.
- A tsunami is not a spectator sport. Do not venture out to watch an approaching tsunami. Remember, if you can actually see the wave, it means you are too close to escape it. Tsunami waves move faster than you can run.
- The danger is NOT over because the first wave has passed. Tsunamis are a series of waves. The other waves may be larger than the first one.

After a Tsunami

- Watch out for animals, especially poisonous snakes that may have entered the buildings along with the water.

- Look out for structural damage to the building before you enter it or opt to stay in it.
- Dysentery and cholera are common occurrences after tsunamis because of the decaying and dead bodies strewn around. Be careful about the water you drink.

Glossary

Earth's Internal Structure

Crust: It is the uppermost part of the Earth. It consists of two distinct parts; the oceanic crust and the continental crust.

Core: The innermost part of the Earth, which is divided into an inner core, the upper boundary of which is 1,700 km from the centre and an outer core, 1820 km thick. Both parts are thought to consist of iron-nickel.

Mantle: The immediate zone of the earth between the crust and the core, accounting for 82 percent of the earth's volume. The mantle is separated from the crust by the Mohorovicic discontinuity and from the core by the Gutenberg discontinuity. It is thought to consist of silicate minerals.

Earthquakes

Active fault: A fault that is likely to trigger another earthquake.

Aseismic: The term refers to a fault on which no earthquake has been observed.

Body wave: Seismic waves that travel either along or near the Earth's surface.

Dip: The angle that a stratum or fault plane makes with the horizontal.

Earthquake: A shaking or trembling of the crust of the Earth caused by breaking and shifting of rock beneath the surface or by underground volcanic process.

Earthquake swarms: Groups of earthquakes, which are concentrated in a certain region, but none of which significantly larger than the others.

Epicentre: The point on the surface of the Earth directly above the focus of an earthquake.

Fault: A fracture in the Earth's crust along which there has been displacement of rock on one side relative to the other. The displacement ranges from a few centimetres to a few kilometres and may occur in horizontal, oblique or vertical direction.

Fault system: Two or more fault sets that are interconnected.

Fault scarp: A steep cliff formed by movement along one side of a fault.

Fault terrace: A step on slope, produced by displacement of two parallel faults.

Fault trace or fault line: Intersection of the fault surface with the surface of the Earth or any other horizontal surface of reference.

Fault throw: The amount of vertical displacement of rocks due to faulting.

Fault Zone: A fault expressed as an area of numerous fractures.

First motion: On a seismogram, the direction of ground motion as the p-waves arrives at the seismometer.

Focal depth: The depth to the hypocentre of an earthquake is called focal depth.

Foreshocks: A tremor, which precedes a larger earthquake or main shock

Geodesy: The branch of science concerned with surveying and mapping the Earth's surface.

Geology: The branch of science concerned with the origin, structure and composition of the Earth.

Geophysics: The branch of science in which the principles of mathematics and physics are applied to the study of the Earth's crust and interior.

Ground failure: A general reference to land slides, liquefaction, lateral spreads and any other consequence of ground shaking.

Ground motion: The movement of the Earth's surface caused by seismic waves and travel through the Earth and along its surface.

Hypocentre: An earthquake is caused by the motion of a fault. The point where the rupture originates is called the hypocentre or the focus.

Inter-plate coupling: It means a fault between two plates is locked and capable of accumulating stress.

Iso-seismal: A contour or line on a map bounding points of equal intensity for a particular earthquake.

Lithosphere: The topmost layer of the Earth's structure forming the plates that take part in the movement of plate tectonics.

Locked fault: A fault that is not slipping because frictional resistance on the fault is greater than the shear stress across the fault. A locked fault is expected to store strain for extended periods. The frictional resistance is eventually overcome in an earthquake.

Love wave: A type of seismic surface wave having a horizontal motion that is transverse or perpendicular to the direction of the propagation of the wave.

Main shock: The largest earthquake in a cluster of earthquakes. The main shock is sometimes preceded by one or more foreshocks but almost always followed by many aftershocks.

P-wave: The primary or the fastest seismic waves travelling away from an earthquake, consisting of a series of compressions and dilatations parallel to the direction of travel of the wave.

Paleoseismic: The history of seismic events, which is determined by examining the layers of rock beneath the surface and how they have been displaced by earthquake in the past.

Plate tectonics: The theory that the Earth's surface consists of a number of plates whose slow but constant motion explain continental drift, mountain formation, etc.

Rayleigh wave: A type of surface seismic wave. It is also known as r-wave.

Recurrence interval: The average interval between two strong earthquakes of similar magnitude in a given location.

Strike-slip fault: A fault on which the two blocks of rocks slide past one another.

Rupture front: The instantaneous boundary between the slipping and locked parts of fault during an earthquake.

Rupture velocity: The speed at which a rupture fault moves across the surface of the fault during an earthquake.

S-wave: A seismic body wave that shakes the ground back and forth perpendicular to the direction of propagation of the wave. It is also called shear wave.

Seismicity: The degree to which a region of the Earth is subject to earthquake.

Seismic movement: A measure of the size of an earthquake derived from the area of fault rupture, the average amount of slip and the force required to overcome the stress generated by the faulting.

Seismic waves: Waves generated by an earthquake. Those that travel either along or near the Earth's surface are called surface seismic waves and those that travel through the Earth's interior are called body seismic waves.

Seismic zone: An area of seismicity.

Seismogenic: Capable of generating earthquake.

Seismogram: The chart of an earthquake as recorded by a seismograph

Seismology: The branch of geology concerned with the study of earthquakes.

Seismometer: An instrument that records the intensity and duration of earthquakes and similar tremors.

Seismoscope: An instrument indicating only the occurrence and time of an earthquake.

Seismic discontinuity: A surface at which velocities of seismic waves change abruptly.

Shearing stress: A stress in which the material on one side of a surface such as a fault plane, pushes on the material on the other side of the surface with a force parallel to the surface.

Slip: The relative displacement of formerly adjacent points on opposite sides of a fault measured on the fault surface.

Slip rate: The rate at which two sides of a fault are slipping relative to one another

Subduction: The process by which one crustal block descends beneath another.

Subduction zone: The place where two crustal blocks come together, one riding over the other.

Surface faulting: Displacement that reaches the Earth's surface during slip along a fault. Surface faulting normally occurs with shallow earthquakes.

Surface wave: Seismic waves that travel along the Earth's surface.

Tectonic: Pertaining to changes in the structure of the Earth's crust; the forces responsible for such deformation or the external forms produced.

Tele-seismic: Pertaining to earthquake at distances greater than 1,000 km from the site of measurement.

Thrust fault: A dip-slip fault in which the upper block above the fault plane moves up and over the lower block.

Tectonics: A branch of geology that deals with the Earth's crustal structure and the forces that produce changes in it.

Volcano

Ash: A common volcanic emission which consists of rock pieces too large to be called dust but smaller than the gravel is called ash. Volcanic ash is not produced by burning.

Caldera: A very large basin-shaped crater formed by the collapse of a volcano when its magma reservoir flows back into the crust. Calderas are found at the tops of volcanoes, where the original peak has collapsed into an empty chamber beneath.

Cinder Cone: A mountain produced by ash or debris tossed from volcano's central crater.

Cinders: Ejected rocks, which are larger than ash but smaller than rocks are called cinders. They are also called scoria.

Crater: A bowl-shaped depression usually formed by explosive events.

Dormant Volcano: Volcano which has still magma. It may or maynot show signs of activity.

Eruption: Ejection of large amount of gas, rock, fragments or lava.

Extinct (Dead) Volcano: A volcano is considered extinct when all its cheque has either called to rock or it has been expelled.

Fissure: A large crack unusually caused by the movements of the tectonic plates along a fault.

Fumaroles: A small vent on a volcano that produces mainly gas.

Lahar: Mud flow formed of a fluid mixture of water and volcanic ash.

Lava: Molten rock that eruption from the volcano's vent and cools to form extrusive igneous rock.

Magma: Molten rock material beneath the Earth's crust from which igneous rocks, are formed.

Phreatic eruption: The bursting of steam from volcano resulting from contact of water with hot rock.

Pumice: Lava containing gases in the form of bubbles when hardens forms a rock, which is peppered with tiny holes.

Tsunami

Gravity wave: A wave in a fluid medium in which restoring forces are provided primarily by buoyancy (that is gravity) rather than compression.

Shallow water: Water of such a depth that bottom topography affects surface waves.

Shallow-water wave: A progressive gravity wave in water whose depth is much less than the wavelength.

Tsunami-genic: Referring to those earthquakes that can generate tsunamis.

Tsunami magnitude: A number that is used to compare sizes of tsunamis generated by different earthquakes.

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